HOMING MECHANISMS AND MATING SYSTEMS OF ATLANTIC COD: EVIDENCE FROM A NEWFOUNDLAND SPAWNING GROUND

MATTHEW J.S. WINDLE

Homing mechanisms and mating systems of Atlantic cod: evidence from a Newfoundland spawning ground

By

© Matthew J.S. Windle

A thesis submitted to the
School of Graduate Studies
in partial fulfillment of the
requirement for degree of
Master of Science

Department of Biology, Faculty of Science
Memorial University of Newfoundland

April 2006

St. John's Newfoundland

Your file Votre référence
ISBN: 978-0-494-19407-2
Our file Notre référence
ISBN: 978-0-494-19407-2

Abstract

This study investigates the movements of Atlantic cod (*Gadus morhua* L.) during the spawning season in Placentia Bay, Newfoundland, and consists of two components. First, transplantation techniques and acoustic telemetry are used to demonstrate that transplanted cod return more successfully to a spawning ground from a traditional migratory pathway compared to cod transplanted to a less-used area, suggesting that familiar landmarks are important to short-distance homing. Second, spatial and temporal patterns of fishing data and acoustic tracking of individual fish are used to document lek-like behaviour of cod at a small-scale spawning ground, including spatial patterns of male-skewed sets, higher proportions of spawning females in male dominated aggregations, and highly mobile movements of cod over the grounds. The results offer insights into spatial learning in ocean migrants, and provide supportive evidence for lekking behaviour in wild cod populations.

Acknowledgements

I wish to express my sincere thanks to my supervisor, Dr. George Rose, for the academic opportunity and cultural experience of graduate work in Newfoundland. It was a privilege and an inspiration to work with someone so knowledgeable and keen of the biological and historical aspects of fisheries science. His insights, patience (especially regarding my many digressions on *Architeuthis*), field assistance and guidance in writing were essential to the completion of this thesis.

I would also like to thank the members of my supervisory committee, Dr. Joseph Wroblewski and Dr. Len Zedel, for providing directional and editorial suggestions during the early and latter stages of the thesis. Thanks as well to Dr. David Schneider for providing statistical suggestions during the early stages of the thesis. I would like to thank the staff at the Marine Institute Library, and in particular Ruth Wilson, for their friendly and prompt service, and for always finding that elusive journal article. Many thanks to the members of the Fisheries Conservation Chair for stimulating discussions on land and at sea, and especially Wade Hiscock, Susan Fudge and Dr. Graham Sherwood for field assistance during the tagging and tracking phases of the thesis. Thanks to Jigger Jim, the Fonz and all the crews of the C.C.G.S. Shamook and C.C.G.S. Teleost for their assistance and light-hearted cheer on the cold North Atlantic.

Funding for this thesis was provided by the Natural Sciences and Engineering Research Council of Canada Industrial Chair in Fisheries Conservation at Memorial University of Newfoundland, a Memorial University graduate fellowship, and by several Masters scholarships from the Government of the Northwest Territories.

Table of Contents

List of Tables

List of Figures

List of Appendices

INTRODUCTION AND OVERVIEW

The Atlantic cod (*Gadus morhua* L.) is a demersal species whose geographic distribution includes distinct stocks on all margins of the north Atlantic (Brander, 1994). Historically the most abundant stock in the northwest Atlantic was the 'northern' cod, which was once distributed from the southern Labrador Shelf to the northern Grand Banks (NAFO divisions 2J and 3KL) and supported an inshore fishery for nearly five centuries (Lear and Parsons, 1993). For the bulk of this stock, which includes distinct coastal and offshore components (Smedbol and Wroblewski, 2002), annual movements involved a spring feeding migration from offshore overwintering areas to inshore coastal zones, and a return migration in the fall to the continental slopes (Templeman, 1966). Spawning took place in a wide range of habitats, from the deeper waters of the continental shelf to shallow coastal embayments (Hutchings et al., 1993).

Following the introduction of mechanized trawlers in the 1950s, dense aggregations of overwintering and spawning aggregations on the Newfoundland-Labrador Shelf were highly vulnerable to fishing pressure, leading eventually to a total collapse of Newfoundland cod fisheries and the declaration of a fishing moratorium in 1992 (Kulka et al., 1995). In the 13 years subsequent to the closure of the fisheries, the offshore component of the northern cod stock has shown little to no sign of recovery (Lilly et al., 2004). In contrast, coastal populations in NAFO Divisions 3K (Rose, 2003) and 3Ps (Lawson and Rose, 2000a) have shown moderate signs of rebuilding, with the south coast population in 3PS sustaining a fishery since 1997.

Given the poor rates of recovery for collapsed Newfoundland cod stocks, there exists a great need for research into aspects of cod reproductive biology that have traditionally been overlooked by fisheries managers. In particular, complex behaviours associated with successful reproduction have potential consequences to recovery if they are disrupted through fishing practices (Rowe and Hutchings, 2003). In the case of northern cod, traditional migratory patterns from offshore to inshore areas were disrupted following the decline of the stock (Rose, 1993), and have not been resumed since the collapse (Lilly et al., 2004). Although such knowledge is important to the rebuilding of northern cod, it is currently unknown how these migratory behaviours are sustained, and by what mechanisms cod navigate over traditional migratory routes. In comparison, migrations and homing in Pacific salmon have received a greater degree of scientific study, with the recognition that survival and successful reproduction is higher in individuals that return to locally adapted environments (Quinn and Dittman, 1990).

The mating system of cod has historically received little consideration by fisheries management agencies despite its significant role in the conservation and rebuilding of stocks (Rowe and Hutchings, 2003). Based on laboratory studies, fishing has the potential to disrupt complex mating behaviours including dominance hierarchies and mate choice, as well as the biased targeting of one sex over the other due to activity levels and spatial distributions (Hutchings et al., 1999). Relatively little is known regarding the mating behaviour of wild cod, thus limiting the interpretation of potential effects of fishing and other sources on cod spawning behaviour and the recovery of collapsed cod stocks. The goals of this thesis are to expand our current understanding of cod

reproductive behaviour through the study of a) homing mechanisms in spawning cod, and b) the mating system of wild cod.

Migrations and orientation mechanisms of Atlantic cod

Historical and commercial interest in the species has produced a large volume of studies focusing on life history traits related to recruitment and harvest, including reproductive biology and the seasonal movements of various stocks (Brander, 1994). As with many marine fish, the reproductive phase of the cod life cycle often involves a migration to and from spawning grounds, where individuals aggregate to disperse their genes (Harden-Jones, 1968). Such migrations may occur annually along broadly defined routes, ranging from tens to hundreds of kilometres (Harden-Jones, 1968; Templeman, 1974; Godø, 1984; Bergstad et al., 1987; Rose, 1993; Bagge et al., 1994; Brander, 1994; Lawson and Rose, 2000a; Comeau et al., 2002a; Rose, 2004).

Despite our understanding of the timing and spatial parameters of cod migrations, mechanisms by which cod navigate over large distances remain unknown. Hypothesized directional clues for migrating cod are numerous, and include the use of hydrographic features (Otterlind, 1985; Rose, 1993; Stensholt, 2001), ambient infrasound (Sand and Karlen, 1986; Godø, 1995), currents and tidal flow (Rose et al., 1995; Wroblewski et al., 2000), compass orientation (Arnold et al., 1994), and the pursuit of prey (Templeman, 1965; Rose, 1993). Recognition of spawning grounds could be accomplished through the use of familiar landmarks (Green and Wroblewski, 2000) or point source attractors, such

as "grunting" sounds of spawning fish (Nordeide and Kjellsby, 1999), or a characteristic sound or geophysical signature (Robichaud and Rose, 2002a).

Research in orientation mechanisms of ocean migrants has been dominated by studies on semelparous salmonid species (Quinn, 1990). Pacific salmon are known to use imprinted olfactory information during their upriver migration (Hasler and Scholz, 1983), although the use of this mechanism in the open ocean and coastal portions of the migration is less certain (Quinn, 1990). As the critical period for imprinting in fishes is thought to occur during some early life history stage (Hasler and Scholz, 1983), it is unlikely that cod are able to recognize their natal spawning grounds using olfactory signals. Cod eggs are pelagic and planktonic, and subsequently drift away from spawning grounds immediately after release (Harden Jones, 1968). The iteroparous reproductive strategy of cod favours spatial learning over imprinting, where new recruits in a fish population are able to learn spatial patterns through repeated experiences (McQuinn, 1997). In some shoaling species, there exists strong evidence that fidelity and migration patterns may be learned through social transmission from older to younger fish (Helfman and Schultz, 1984). Observations of juvenile cod accompanying larger, migrating adults suggest that spatial learning may be an important factor of cod migration and the recognition of traditional spawning grounds (Rose, 1993).

Landmark usage by orienting fish has been reviewed by a number of authors (e.g. Dodson, 1988; Braithwaite, 1998), with many examples provided by *in situ* (Aronson, 1951; Reese, 1989; Mazeroll and Montgomery, 1998) and *ex situ* (Waburton, 1990; Odling-Smee and Braithwaite, 2003) experiments. Landmarks can be categorized into

two types, local (near) or global (distant), and may consist of many different structures and modalities (Braithwaite, 1998). Fish may use a specific sequence of landmarks to follow a route, or may incorporate landmarks into a familiar area map that allows a more flexible behaviour in terms of route selection (Dodson, 1988). For example, butterflyfishes migrating within their home ranges use coral heads as landmarks along foraging paths (Reese, 1989).

The potential for spatial learning may be higher for cod populations that reside year-round within a relatively small geographic range, particularly inshore embayments. The cod stock within NAFO Subdivision 3Ps is currently the largest in Newfoundland waters, and has a significant coastal population in Placentia Bay (Lawson and Rose, 2000a; Brattey et al., 2002). Cod have been found to spawn at specific locations within the bay, most notably the Bar Haven grounds located among the inner islands (Lawson and Rose, 2000b). Peak spawning occurs in April and May, following which many cod migrate out of the bay for summer feeding, predominantly along the eastern channel (Lawson and Rose, 2000a). This same migration route is used by cod returning to the inner bay in the fall (Lawson and Rose, 2000a), where part of the population overwinters (Mello and Rose, 2005a). Given the persistent use of their relatively short migration route (~100 km), cod moving within Placentia Bay may learn to recognize familiar features in order to successfully navigate to their destination. A recent homing experiment in Placentia Bay found that transplanted cod returned more successfully from locations along the familiar migration route in the eastern channel, suggesting that spatial memory plays an important role for navigating cod (Robichaud and Rose, 2002a).

However, these results were confounded by other possible explanations, especially varying release site distances from the spawning ground. To date, spatial familiarity as a means of navigation has not been directly tested in wild cod.

Spawning behaviour of Atlantic cod

In the northeast Atlantic, cod spawn along the continental shelf and in coastal bays at depths ranging from tens to hundreds of metres (Rose, 1993; Brander, 1994; Smedbol and Wroblewski, 1997). Spawning periods range from early spring to late summer, and generally begin progressively later southward (Scott and Scott, 1988). Cod are broadcast spawners, and may reproduce at temperatures at or below 0° C (Lawson and Rose, 2000b). Spawning may occur over broad geographic areas (Hutchings et al., 1993; Rose, 1993; Morgan and Trippel, 1996) or at discrete, traditional sites (Lawson and Rose, 2000b). The locations of spawning grounds may optimize local retention of developing eggs and larvae (Bradbury et al., 2000).

Insights into the spawning behaviour of cod have relied largely on captive studies. During the weeks preceding spawning in tank enclosures, larger male cod move away from female aggregations and defend small territories through agonistic male-male interactions (Brawn, 1961a; Hutchings et al., 1999). When ready to spawn, females move into these territories and initiate male courtship displays that include flaunting, circling, and grunting sounds produced by muscles surrounding the swim bladder (Brawn, 1961a; Hutchings et al., 1999). Sound production by males has been

hypothesized to be a sexually selected trait that may influence female mate choice (Hutchings et al., 1999; Engen and Folstad, 1999). Females may be able to assess the quality of potential mates based on loudness of grunting noises, as the drumming muscle mass of spawning males has been positively correlated with body size, condition, and fertilization potential (Rowe and Hutchings, 2004). Following mate selection, spawning partners engage in a ventral mount in which the male grasps the female from beneath using pelvic fins and aligns the urogenital pores for external fertilization of the eggs. Females are batch spawners, with larger individuals capable of releasing millions of eggs in up to 19 batches over several months (Kjesbu, 1989; Chambers and Waiwood, 1996). Among males there is typically a high variance in reproductive success (defined as the number of paired spawnings), with larger individuals able to spawn with more frequency (Brawn, 1961a; Hutchings et al., 1999; Bekkevold et al., 2002). Spawning pairs are often accompanied by satellite males, which may contribute significantly to the fertilization of eggs (Hutchings et al., 1999; Rakitin et al., 2001; Bekkevold et al., 2002). No parental care is provided to the offspring.

At sea, the spawning behaviour of wild cod has been interpreted using fishing catches and remote techniques such as acoustic surveys and telemetric tracking. During the spawning season, cod are highly aggregated and spawn in dense shoals near the ocean floor (Rose, 1993). On several occasions, "spawning columns" extending vertically above spawning aggregations have been observed (Rose, 1993; Lawson and Rose, 200b), although the function of such structures remains unknown. Males appear to establish spawning sites prior to the arrival of females, as shown by male dominated catches early

in the spawning season (McKenzie, 1940; Morgan and Trippel, 1996; Nordeide, 1998; Lawson and Rose, 2000b). A large scale analysis of fishing sets collected on the Grand Banks revealed that cod form both male dominated and female dominated aggregations, with a large degree of spatial separation between the two types (Morgan and Trippel, 1996). Furthermore, male dominated catches had higher proportions of spawning cod relative to equal sex ratio and female dominated catches (Morgan and Trippel, 1996), supporting laboratory observations that females move into male territories when ready to spawn. However, a linkage between male dominated areas and female spawning activity has yet to be established at the smaller and realistic spatial resolution of local spawning grounds in Newfoundland waters.

The collective results of laboratory and field studies are reshaping the long-held notion that cod are promiscuous group spawners. Citing evidence largely derived from tank experiments, several authors have noted that cod fulfill many of the prerequisites of a lekking mating system (Hutchings et al., 1999; Nordeide and Folstad, 2000). Leks are defined as aggregations of males that females visit solely for the purpose of mating, and share common characteristics: a lack of paternal care; an arena site that is used solely for the purposes of mating; the inability of males to monopolize resources required by females; and female mate choice (Höglund and Alatalo, 1995). Lekking behaviour was first described in birds, although similar behaviour has been noted in several families of teleost fishes (Loiselle and Barlow, 1978; McKaye, 1983; Gladstone, 1994; Wedekind, 1996; Donaldson, 1995; Figenschou et al., 2004). While the spawning behaviour of captive cod is largely consistent with a lekking strategy, corresponding field observations

are relatively lacking. To date, the lekking hypothesis has not been directly tested in wild cod populations.

The Bar Haven spawning grounds represented an ideal location to investigate potential lek-like behaviour in cod. Located in the inner part of Placentia Bay, the grounds are easily accessed by small boat and are characterized by a series of islands separated by relatively shallow channels (< 90 m). During the spawning season, aggregations of cod are typically found on the slopes of the shallow banks surrounding the islands, most notably the "Corner Bank" area off the northeast shore of Bar Haven Island. Fish sampling sets directed at cod spawning aggregations have been collected since 1997 at various locations in the area, and suggest that males arrive first, followed by females and immature individuals (Lawson and Rose, 2000b). A study by Robichaud and Rose (2003) found that acoustically tagged cod exhibited sexual differences in residency times on the spawning ground, with males more likely to be relocated than females on a given survey. However, the locations of any lekking arenas on the Bar Haven grounds remain unknown.

Thesis Overview

In this thesis I use biotelemetric techniques to investigate two aspects of the reproductive cycle of Atlantic cod: the mechanisms by which cod are able to locate traditional spawning sites, and the spawning behaviour of cod over these sites. In the first component of the thesis, I use acoustic telemetry and transplantation techniques to

investigate the hypothesis that spatial familiarity is important to the successful homing of cod to a spawning ground. The second component of the thesis was concerned with examining lek-like behaviour in cod at a well-established spawning ground, using spatial patterns of fish distribution based on acoustics and research catches, in addition to telemetry of individually tagged fish. I then discuss my results with respect to hypothesized orientation mechanisms and mating systems of Atlantic cod.

CO-AUTHORSHIP STATEMENT

I am the principal author of all research papers presented in this thesis. I was responsible for the planning, design and data collection of all experiments, as well as data analysis and manuscript preparation. Dr. George A. Rose is second author on all papers, and provided conceptual suggestions and aid during all stages of the thesis, including editorial comments on previous drafts.

Publication and submission status:

Chapter 1 (Windle and Rose) was published in September 2005 in *Fisheries Research*, Volume 75, Issues 1-3, Pages 193-199

Chapter 2 (Windle and Rose) is in press in *Marine Biology*

CHAPTER 1. MIGRATION ROUTE FAMILIARITY AND HOMING OF TRANSPLANTED ATLANTIC COD (*GADUS MORHUA*)

1.1 Abstract

To investigate migration route familiarity and homing success of Atlantic cod (*Gadus morhua* L.), acoustically tagged spawning cod caught at the Bar Haven spawning ground, Placentia Bay, Newfoundland, were transplanted 21 km along their migratory pathway and 21 km in the opposing direction. A control group was released where caught. Transplanted groups included fish of both sexes and 2 size classes (58-60 cm and >70 cm). Tagged cod were then relocated using biotelemetry. All 16 control fish were relocated at Bar Haven. Twelve of 32 transplanted fish had known fates (7 returned to Bar Haven, the earliest 12 days after release, and 5 died). Significantly more cod returned from the migratory pathway (adjusted rate of 51%) compared to cod released outside of this area (13%). Small males showed the highest same year homing rates (88%): large females the poorest (0%). After one year at large, significantly more cod released in the migratory pathway returned to Bar Haven during the spawning season, suggesting that cod may repeat the migratory behaviour of previous years.

1.2 Introduction

Annual movements to spawning grounds follow established patterns along broadly defined migratory routes for many Atlantic cod (*Gadus morhua*) populations (Harden-Jones, 1968; Templeman, 1974, Godø, 1984; Bergstad et al., 1987; Rose, 1993; Bagge et al., 1994; Lawson and Rose, 2000a; Comeau et al., 2002a). Recently, acoustic

telemetry has been used to demonstrate multiyear homing of individual cod to a spawning ground (Robichaud and Rose, 2001), as well as the ability of transplanted cod to home to a spawning ground over relatively short distances (Green and Wroblewski, 2000, Robichaud and Rose, 2002a). However, the mechanisms by which cod are able to navigate and recognize spawning grounds remain unclear.

The gregarious behaviour of migrating fish may point to underlying social mechanisms of migration (e.g. Helfman and Schultz, 1984; Corten, 2002). Younger, naïve fish may learn spatial sequences from more experienced members of an aggregated population (Rose, 1993; McQuinn, 1997), using familiar landmarks to pilot along a consistently used route (Mazeroll and Montgomery, 1998). Robichaud and Rose (2002a) observed that transplanted cod appeared to home more successfully from a site along a familiar migratory pathway than from a less-used area, but could not draw any firm conclusions because their release sites were at different distances from the spawning ground.

In keeping with the theory of social transmission, there are indications that the size and age of cod may influence their migrations. Harden-Jones (1968) cited evidence that late juvenile cod may accompany spawning migrations in "dummy runs". Rose (1993) observed size-structured cod aggregations migrating across the Newfoundland shelf, with larger "scouts" at the leading edge and smaller individuals following to the rear. In the southern Gulf of St. Laurence, autumn migrations have begun progressively earlier as older individuals have become more numerous (Comeau et al., 2002b).

I hypothesized that spatial learning and so-called 'conservatism' (Corten, 2002) could account for how cod migrate to and locate a spawning ground. In this work, I investigated the spatial learning hypothesis by transplanting groups of acoustically tagged cod in spawning condition equal distances from the spawning ground back along their migratory pathway and in the opposite direction. Homing movements were then monitored using biotelemetry. Transplanted groups included fish of both sexes and size classes of 58-60 cm and >70 cm, in an attempt to investigate homing behaviour by sex and age.

1.3 Materials and methods

The study was conducted in the inner part of Placentia Bay, Newfoundland (NAFO Subdivision 3Ps), near Bar Haven and Woody Islands (Figure 1.1). The 3Ps cod stock is currently the largest in Newfoundland waters, and has recently been the focus of studies examining migratory movements, exploitation rates, and spawning activity (Lawson et al., 1998; Lawson and Rose, 2000a; Brattey and Healey, 2003). Within Placentia Bay, there is evidence of a coastal population that spawns most consistently near Bar Haven Island (hereafter the Bar Haven spawning grounds; Figure 1.1; Lawson and Rose, 2000a; Brattey and Healey, 2003). Seasonal migrations in and out of the inner Bay occur in late spring (outgoing) and fall (incoming) along the eastern channel (Lawson and Rose, 2000a). Spawning aggregations and behaviour have been observed at Bar Haven at depths from 15 m to 80 m (S. Fudge and G.A. Rose, unpublished data).

Multiple current mooring experiments have shown that the mean circulation for

Placentia Bay is in a counter-clockwise direction (Schillinger et al., 2000). The most recent available measurements of current headings and magnitudes within the inner part of Placentia Bay are derived from Acoustic Doppler Current Profilers (ADCPs) moored in the eastern channel (47° 24.56'N, 54°04.27'W) and western channel (47° 24.63'N, 54°24.17'W) of the bay during the period of April 18-June 28, 1999 (Schillinger et al., 2000). Mean current vector components at the eastern channel mooring were u = 10.96 cm s^{-1} ± 28.76 SD (u = eastward component) and v = 8.48 cm s^{-1} ± 15.70 SD (v = northward component) at 20 m, and u = -1.06 cm s^{-1} ± 6.99 SD and v = 2.50 cm s^{-1} ± 5.08 SD at 45 m. Mean current vector components at the western channel mooring were u = -7.55 cm s^{-1} ± 15.56 SD and v = 0.92 cm s^{-1} ± 8.78 SD at 20 m, and u = -2.46 cm s^{-1} ± 7.72 SD and v = -0.73 cm s^{-1} ± 3.84 SD at 45 m. No correlation was found between wind stress and observed currents at any depth (Schillinger et al., 2000).

In early April, 2002, pre-spawning aggregations of cod were located using an EK500 echosounder (38 kHz) on the Bar Haven grounds in depths ranging from 15-50 m and temperatures near 0 °C. On April 12 and 14, individual cod from these aggregations were caught using hand lines and featherhooks and brought gently and slowly to the surface to reduce stress and the risk of pressure trauma. Fish were then measured, and individuals within 58-60 cm and > 70 cm length ranges were placed in two holding tanks (1.3 m x 1.3 m x 1.3 m). A continuous supply of fresh seawater (0.5°C) was pumped into the tanks.

For each fish, weight and total length were measured, and sex was determined by cannulation of the genital opening, to a depth of 1-2 cm and examining for the presence

of either eggs or milt. Returns of previously tagged pre-spawning cod sexed by cannulation have indicated 100% accuracy (G.A. Rose, unpublished data). Only mature individuals in spawning condition and deemed to be in excellent health were used in the study. Each fish had a coded acoustic transmitter (Lotek Model CAFT16-2; 82 mm long x 16 mm diameter; 34.2 g in air, 18.1 g in water) surgically implanted into the body cavity, and a t-bar anchor tag (Floy FD-68BC) inserted into the musculature adjacent to the first dorsal fin. Control fish were observed for up to 2 hours prior to release at the tagging site, while transplanted fish of necessity were held longer (up to 9 hours) due to transport time. The behaviour of all tagged fish was monitored for signs of stress including swimming difficulties and buoyancy problems. A few experienced difficulties and were culled from the experiment. All procedures were approved by the Animal Care Committee of Memorial University.

Approximately equal proportions of randomly selected small (58-60 cm) males, small females, large (>70 cm) males, and large females, were released at each site. The release sites for transplanted groups in the eastern (Haystack Bank) and western (White Islands) channels of Placentia Bay were selected based on their similar bathymetry (≅ 50 m depth), centered positions within the channels, and equal distances from the spawning ground at Bar Haven (≅ 21 km). Haystack Bank is located on the migration route into and out of the bay, while the White Islands are well outside this area. On April 12, 16 cod (71-85 cm) were tagged and released in two batches at the eastern (n=9) and western (n=7) sites (Figure 1.1). On April 14, an additional 16 cod (58-60 cm) were tagged and transplanted in groups of eight at the two sites, and a control group was tagged and

released at the spawning grounds. All transplanted and control groups had equal sex ratios. A sentinel tag was dropped to the ocean floor near the control release site for tests of receiving distances.

Relocation surveys of tagged fish were run on 7 days, beginning April 18 and ending on May 2, 2002, from a 7 m vessel (RV "Gecho") outfitted with a 50 and 200 kHz Furuno echosounder and Lotek (Model SRX-400) sonar tag receiver. Listening stations were occupied on a grid over the spawning ground, covering an area approximately 25 km^2 (Figure 1.1). The spatial extent of the listening grid was determined by the presence of spawning fish in acoustic surveys conducted prior to this experiment and reinforced by soundings conducted during the telemetric surveys. Based on field trials to determine the detection range of the sentinel tag, stations were spaced 0.25 nautical miles (NM) apart. At each station, with vessel engines off to reduce noise, an omnidirectional hydrophone (Lotek Model LHP-1) was lowered into the water and tag frequencies (65.5 kHz for males, 76.8 kHz for females) alternately monitored for 10 seconds. The positions of relocated fish were determined using an onboard NorthStar GPS (accuracy to within a few m). Where weather conditions impeded complete coverage of the survey grid within a single day, listening stations over the non-surveyed portions of the grid were resumed at the earliest opportunity. During the 2003 spawning season, telemetric surveys were conducted periodically from April 8 to May 16 in the same area, utilizing similar listening stations as well as sites identified by acoustic surveys. Release locations in the eastern and western channels were surveyed periodically from April to June 2002 and April to May 2003 to monitor the activity of transplanted cod.

A homing equation adapted from Robichaud and Rose (2001) was used to estimate the adjusted proportion of transplanted cod that returned to the spawning ground:

$$\frac{(\text{Homed} / E) + \text{Captured}}{\text{Released} - \text{Mortality}} = \text{Homing Rate} \qquad (1)$$

where *Homed* indicates the number of tagged cod that were relocated at the Bar Haven grounds through the use of telemetry or returns from the fishery, *Captured* indicates the known number of tagged cod that were caught away from the grounds during the commercial fishery, and *Released* indicates the total number of tagged cod. Mortality refers to tags that were consistently relocated at the transplantation sites over the two-year study period, where it was assumed that these fish had either died or expelled the transmitters. Tests of the detection rage of the sentinel and dead fish tags indicated that variability in bathymetry of the shallow spawning ground greatly affected the reflection and attenuation of the acoustic signal from transmitters. Thus, not all fish present are detected on any survey. Kaunda-Arara and Rose (2004) reported comparable effects in a tropical reef using similar equipment. Hence, a relocation efficiency (E) based on the average daily relocation rate of control fish for a complete survey (0.7) was applied to the number of transplanted cod relocated in calculations of homing rate. Fisher's exact test was used to investigate significant differences between homing proportions of east and west transplanted groups, males and females, and size classes.

1.4 Results

The telemetric surveys over the spawning ground relocated 22 of the 48 fish released, including all 16 control fish and 6 transplanted cod (Table 1.1). The first returning transplant was detected on April 25, 11 days after release. After that, 5 more transplants were detected at the grounds in quick succession. All transplants were relocated along the eastern edge of Woody Island (Figure 1.2). One transplant that was not detected was subsequently caught at the spawning grounds in 2002. Relocations declined for all groups towards the end of April.

A total of 5 of the 16 cod released at the eastern site were relocated in 2002 at Bar Haven (adjusted homing proportion of 0.51; Table 1.1). Of cod transplanted to the western channel only 1 small male was relocated at the spawning grounds, on April 25 (adjusted homing proportion of 0.13). Homing proportions differed between eastern and western releases (Fisher's exact test, $p = 0.042$; Table 1.2). Surveys of the translocation sites on April 20-22 and June 12, 2002 consistently relocated four tags at the western channel site and one tag at the eastern site. It was assumed that these tagged cod had either died or expelled their transmitters.

Of the 7 transplanted cod that homed to the spawning ground within the spawning season, 6 (83%) were from the smaller size class (58-60 cm). The majority of homing cod were males (71%). Although the proportions of small fish were statistically greater than large fish (Fisher's exact test, $p = 0.004$; Table 1.2), the small sample sizes indicate caution in interpretation. Tagged cod within the smaller size class (58-60 cm) could have been 5-10 years old, while cod over 70 cm were likely all > 7 years old, based on otolith-

determined ages of 78 cod caught from the same aggregation as the tagged fish (Figure 1.3).

After one year at large, a total of eight tagged cod were relocated at the Bar Haven spawning grounds during the 2003 spawning season. Adjusted homing proportions for eastern, western and control cod in 2003 were 0.79, 0.22 and 0.49 respectively (Table 1.3), with homing significantly different between eastern and western transplanted cod (Fisher's exact test, $p = 0.049$; Table 1.4). Homing rates did not differ significantly between size classes or sexes (Table 1.4).

1.5 Discussion

The homing results of cod transplanted to areas within and outside their familiar migratory pathway support the hypothesis that cod use familiar features to navigate towards a spawning ground. Significantly more cod returned from the release site on the migratory pathway than from a site well removed from it. Homing was not as rapid as in previous studies using short translocation distances (Green and Wroblewski, 2000; Robichaud and Rose, 2002a).

Nevertheless, homing proportions between size classes did not follow expected results, as smaller cod exhibited a higher homing tendency than did larger individuals. This result suggests that learning of migratory routes may occur prior to first spawning and at smaller sizes than were used in this study. Immature cod are known to make "dummy runs" with older spawning fish (Harden-Jones, 1968; Rose, 1993), and may learn spatial information along routes during this life history stage. In the acoustic

surveys that preceded the tagging, approximately 22% of the cod sampled from the spawning aggregation at Bar Haven were young, immature individuals. Although it cannot be determined if these cod migrated with the aggregation or were simply recruited at the spawning site, similar proportions of immature cod (29.5%) were found in migratory shoals sampled in 2001 in the eastern channel prior to spawning. In addition, the differences in the size classes available to be tagged was not great enough to preclude an overlap of ages. Some of the smaller fish were likely to have been multiple year spawners.

It is possible that the prevailing counter-clockwise currents in Placentia Bay provided a transport mechanism for cod returning from the eastern translocation site. However, metered current moorings have recorded substantial variations in current direction at various depths in the eastern channel of Placentia Bay (Schillinger et al., 2000), suggesting a high degree of uncertainty in possible drift directions and net transport. Furthermore, any movement with prevailing currents is more likely to be a result of active rather than passive transport. Observations of the selective use of currents by migrating cod (Arnold et. al., 1994; Rose et al., 1995; Wroblewski et al., 2000), as well as observed migrations of post-spawning cod moving against the prevailing currents in Placentia Bay (Lawson and Rose, 2000a) support this claim. It is unclear how prevailing currents may provide directional clues to homing cod. The higher homing rate of the eastern transplants is contrary to expectations if a chemical point source was being used as a short-range navigation mechanism, as the eastern release site is upcurrent of the spawning ground.

Following one year at large, the tagging group with the most returns to the Bar Haven grounds were cod transplanted to the migratory pathway, suggesting that cod repeat the homing behaviour of previous years. The proportions of the fish at large that were caught prior to 2003 were somewhat higher (0.29) than those estimated for this stock using conventional tagging methods (0.2; Brattey and Healey, 2003). The different groups did not differ in proportions caught, which suggests there were no differences in survival past the immediate effects of tagging. I attribute the higher immediate mortality in the transplanted fish to the stress of transport.

In conclusion, the present study provides support for the hypothesis that spatial familiarity is a key factor in cod homing. Familiarity with migratory routes may be learned as young cod are recruited to spawning aggregations, and reinforced through multi-year migrations and site fidelity. Similar socially transmitted behaviour has been suggested for the Atlantic herring (*Clupea harengus*) (McQuinn, 1997; Corten, 2002) and plaice (*Pleuronectes platessa*) (Hunter et al., 2003). Migration mechanisms remain difficult to specify in studies at sea. However, the present study suggests progress may be made by sonic tagging of larger numbers of cod, and the transplantation of smaller fish with new generations of smaller tags to determine the ontogenic development of homing ability and site fidelity.

Table 1.1 Homing proportions for all categories of cod that were transplanted ~21 km from the Bar Haven (BH) spawning ground. Homing was adjusted by the relocation efficiency of the telemetry gear, derived from the average daily relocation rate of the control cod (0.7).

	Released	Tagging Mortality	Relocated at BH	Caught at BH	Relocation Efficiency	Homed
	A	*B*	*C*	*D*	*E*	[(*C*/*E*)+*D*]/(A-B)
Control	16	0	16	0	0.7	--
Transplanted Groups						
East	17	1	5	1	0.7	0.51
West	15	4	1	0	0.7	0.13
All males	15	2	4	1	0.7	0.52
58-60 cm males	8	2	3	1	0.7	0.88
> 70 cm males	7	0	1	0	0.7	0.20
Females	17	3	2	0	0.7	0.20
58-60 cm females	8	1	2	0	0.7	0.41
> 70 cm females	9	2	0	0	0.7	0.00
All 58-60 cm cod	16	3	5	1	0.7	0.63
All > 70 cm cod	16	2	1	0	0.7	0.10

Table 1.2 Results of Fisher's exact test comparing homing proportions of cod transplanted to the eastern and western channels of Placentia Bay. Homing refers to the number of cod relocated at BH [adjusted by the relocation efficiency of the telemetry gear (0.7)] and cod that were captured at BH during the 2002 spring fishery.

	Homed	**Not Homed**	**Total**	**p-value (2-tail)**
East	8	8	16	
West	1	10	11	
Total	9	18	27	0.042
Males	7	6	13	
Females	3	11	14	
Total	10	17	27	0.120
All 58-60 cm cod	8	5	13	
All > 70 cm cod	1	13	14	
Total	9	18	27	0.004

Table 1.3 Homing proportions for tagged cod relocated during the 2003 spawning season at Bar Haven (BH). Homing was adjusted to account for: the relocation efficiency of the telemetry gear, taken as the average daily relocation rate of the control cod over the spawning grounds (0.7) during the 2002 spawning season; the number of tagged cod caught in the seasonal fishery prior to the 2003 spawning season; and an estimated annual survival rate (0.8).

	Released	Tagging Mortality	Caught (%)	Relocated at BH	Homed
	A	*B*	*C*	*D*	$(D/0.7)/[(A-B-C)*(0.8)]$
Control	16	0	5 (31)	3	0.49
Transplanted Groups					
East	17	1	7 (44)	4	0.79
West	15	4	3 (27)	1	0.22
Male	15	2	3 (23)	5	0.89
Female	17	3	7 (50)	3	0.77
All 58-60 cm cod	16	3	3 (23)	4	0.71
All > 70 cm cod	16	2	7 (50)	4	1.00

Table 1.4 Results of Fisher's exact test comparing homing proportions of transplanted cod relocated during the 2003 spawning season at Bar Haven (BH). Homing includes the number of cod relocated at BH during telemetric surveys, adjusted by the relocation efficiency of the telemetry gear (0.7).

	Homed	**Not Homed**	**Total**	**p-value (2-tail)**
East	6	3	9	
West	1	7	8	
Total	7	10	17	0.049
Males	7	3	10	
Females	4	3	7	
Total	11	6	17	0.338
All 58-60 cm cod	6	4	10	
All > 70 cm cod	6	1	7	
Total	12	5	17	0.643

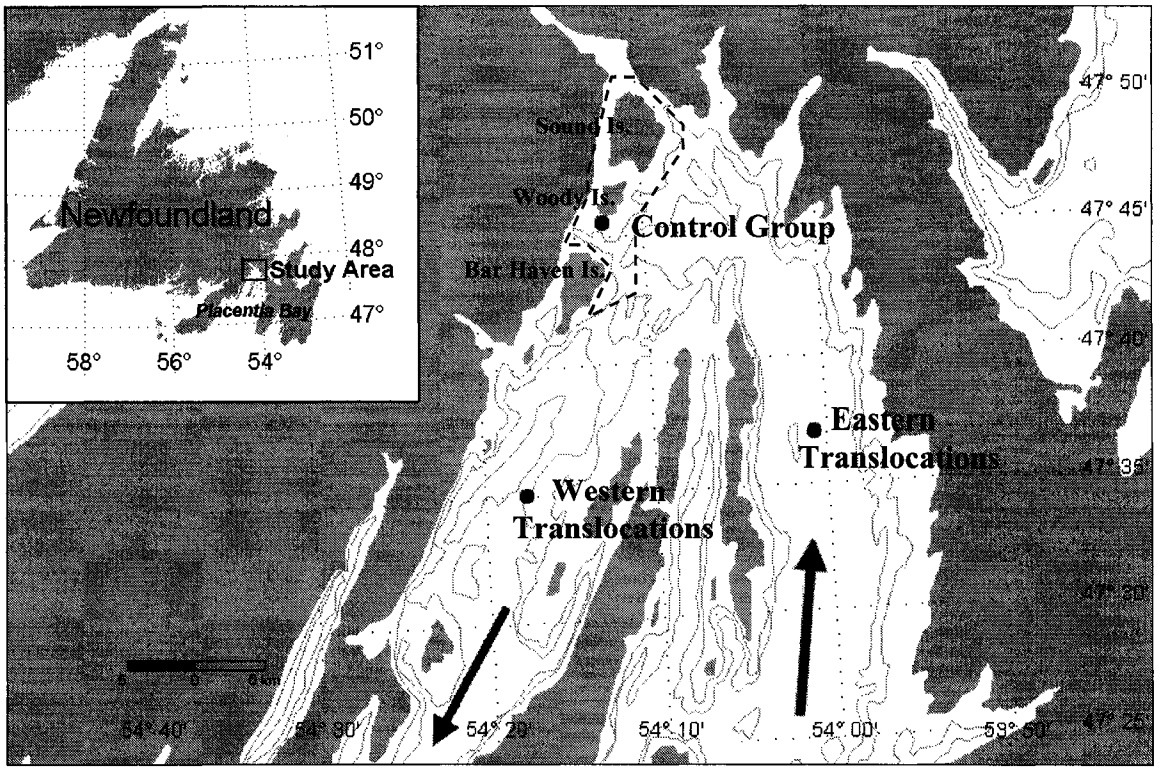

Figure 1.1 Map of Newfoundland (insert), showing the location of the study area in the inner part of Placentia Bay. The mean circulation of currents is in a counter-clockwise direction (black arrows), with 50 m and 100 m depth contours shown in grey. The release locations for the control and transplanted groups of tagged cod are indicated by filled circles. The area within the dashed line indicates approximate survey coverage of the spawning grounds. Release sites for transplanted groups in the eastern (Haystack Bank) and western channels (White Islands) of Placentia Bay were similar in bathymetry (≅ 50 m depth), positions within the channels, and distances from the spawning ground at Bar Haven (≅ 21 km).

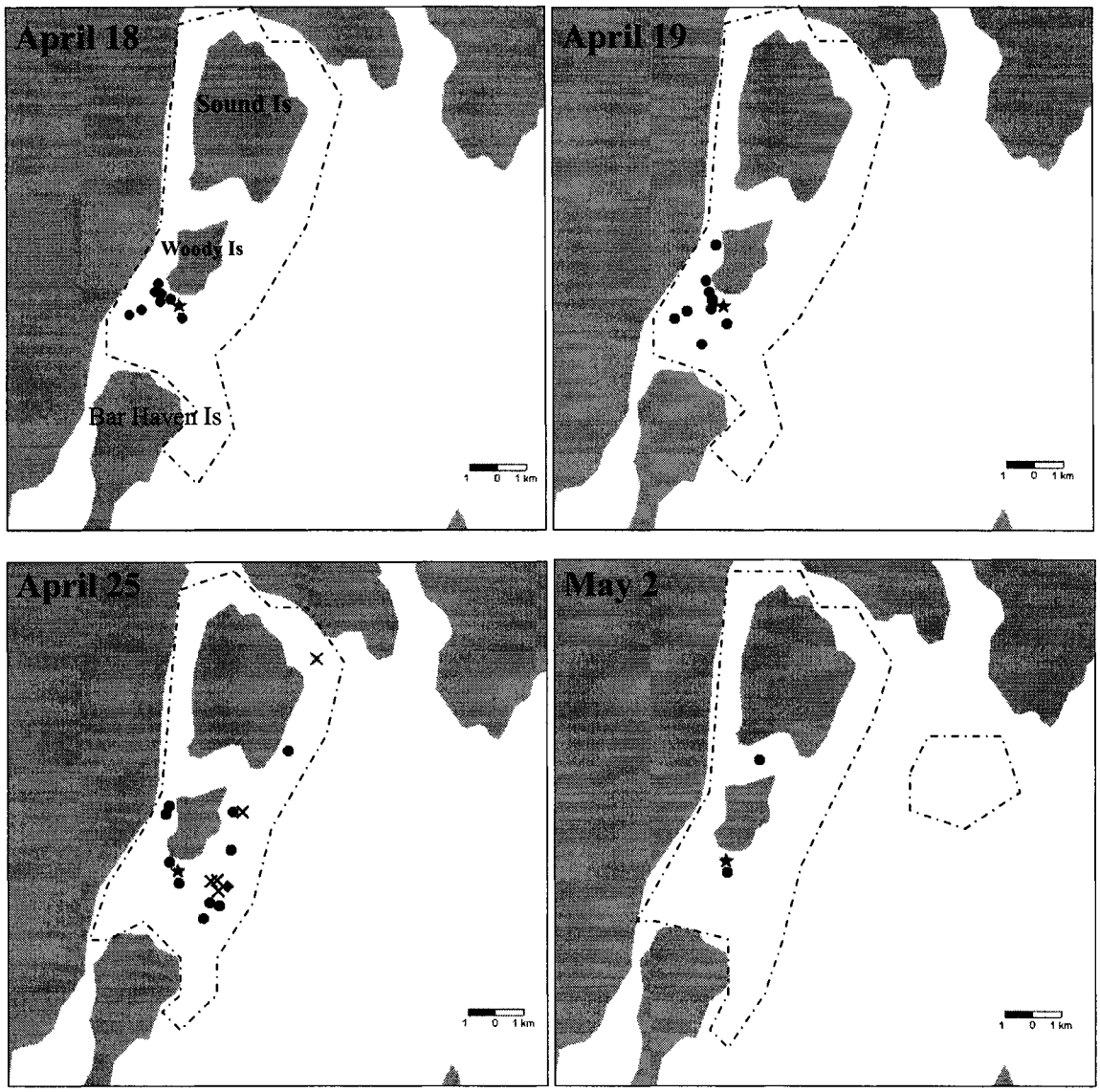

Figure 1.2 Relocation of control (circles), eastern (X) and western (triangles) transplanted cod near control group release site (star). Transplanted cod were not relocated until April 25, after 11 days at large. Telemetric survey coverage for April 20-24 was limited due to poor weather conditions. Survey coverage for all dates is shown within the dashed outline.

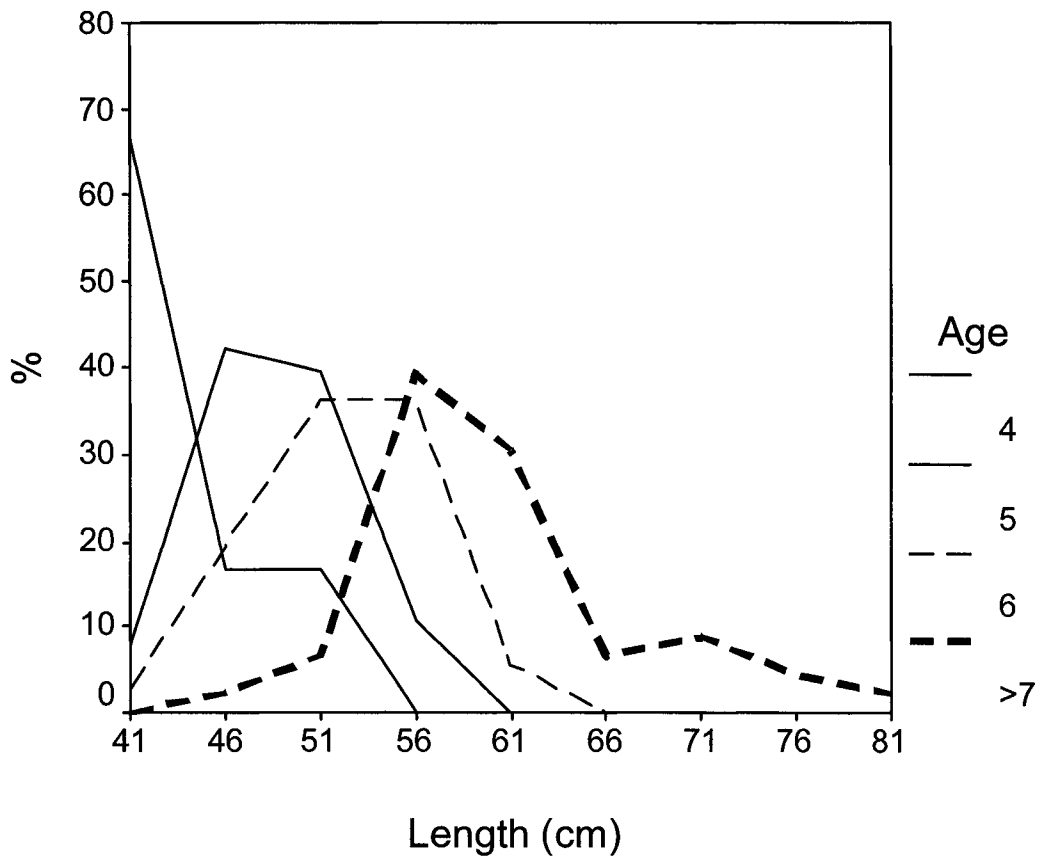

Figure 1.3 Length-age distributions of cod sampled at the Bar Haven spawning grounds in Placentia Bay, Newfoundland, during April 2002 (n=126). The length-based percentages of fish aged four (solid line), five (dotted line) and six (dashed line) are shown, with fish ≥ 7 years (heavy dashed line) grouped as one category. A high variation in age was observed for cod 56-61 cm.

CHAPTER 2. DO COD FORM SPAWNING LEKS? EVIDENCE FROM A NEWFOUNDLAND SPAWNING GROUND

2.1 Abstract

A combined approach linking research fishing data and acoustic telemetry was used to investigate lek-like behaviour in Atlantic cod (*Gadus morhua* L.) at a small-scale spawning ground (~25 km^2) in Placentia Bay, Newfoundland. Analysis of 42 fishing sets collected from 1998 to 2003 revealed the presence of male-skewed sets early in the spawning season (April) in 5 of 6 survey years. Male-skewed sets were consistently distributed at depths < 50 m. The proportions of spawning females and spent males were significantly higher in male-skewed sets, while sets with equal sex ratios had significantly higher proportions of immature males and spent females. Cod of both sexes were significantly larger in male-skewed sets. Telemetric tracking of 25 cod in 2002 and 2003 (12 males, 13 females) tagged during the spawning seasons revealed no specific areas of the grounds that were dominated by either sex, or any stable patterns of tagged males. On average, males and females did not differ in their movements during or between survey days. Cod were highly mobile on the spawning ground. These results suggest that females move into male aggregations to spawn, and provide small-scale field evidence in support of a cod lekking-mating system.

2.2 Introduction

Lek-like mating systems are known or suspected to occur in several families of teleost fishes (Loiselle and Barlow 1978; McKaye 1983; Gladstone 1994; Wedekind

1996; Donaldson 1995; Figenschou et al. 2004). The term 'lek' refers to the temporary aggregation of sexually active males on an arena, where they may hold small territories and display for the purposes of attracting a mate. General prerequisites for lekking include: a lack of paternal care; an arena site that is used solely for the purposes of mating; the inability of males to monopolize resources required by females; and female mate choice (Höglund and Alatalo 1995).

Recently, it has been noted that Atlantic cod (*Gadus morhua*) fulfill many of the conditions of a lekking mating system (Hutchings et al. 1999; Nordeide and Folstad 2000; Rowe and Hutchings 2003). Supportive evidence comes largely from several independent laboratory studies that have documented courtship displays, male-male competition and female mate choice among captive spawning cod. In the weeks preceding spawning, males in tank enclosures establish size-based dominance hierarchies in which larger, more aggressive males are able to defend small territories that are either horizontally (Brawn 1961a) or vertically (Hutchings et al. 1999) separated from the main aggregation of females. Females enter these territories when ready to spawn, and initiate courtship rituals that culminate in a ventral mount by a male and the broadcast release of sperm and eggs. Following spawning, females return to areas outside male territories (Brawn 1961a; Hutchings et al. 1999). Approximately 17-19 batches of eggs may be released by a female during a single spawning season, with no parental care provided by either sex (Kjesbu 1989). Reproductive success is typically skewed towards larger males, although smaller satellite males may also contribute to fertilization through alternative reproductive strategies (Brawn 1961a; Hutchings et al. 1999; Bekkevold et al. 2002). The

spawning activity of captive cod has been reported to increase at night (Brawn 1961a; Kjesbu 1989; Hutchings et al. 1999).

At sea, some support for cod lekking behaviour has come from temporal and spatial trends of sex-skewed catch data. Males appear to establish spawning sites, as shown by male-biased catches at all stages of the spawning season (McKenzie 1940; Morgan and Trippel 1996; Nordeide 1998; Lawson and Rose 2000b). On the Grand Banks, areas where male dominated catches occurred were found to have higher proportions of males and females in spawning condition relative to areas with equal or female-skewed sex ratios (Morgan and Trippel 1996), supporting laboratory observations that females move into male aggregations when ready to spawn. However, the Grand Banks study had females removed from male dominated areas by hundreds of kilometres. While male dominated areas and cod spawning activity have previously been linked at small spatial scales at the Lofoten spawning grounds in Norway (Nordeide 1998), the relationship has yet to be investigated at the spatial resolution of discrete spawning grounds in Newfoundland waters. Furthermore, there has not been any attempt to directly test the lekking hypothesis in a wild cod spawning aggregation.

Along the south coast of Newfoundland, cod spawn at discrete near-shore locations (Lawson and Rose 2000b; Bradbury et al. 2000; Brattey and Healey 2003). In Placentia Bay, individual cod exhibit a high degree of site fidelity to the Bar Haven spawning grounds over multiple years (Robichaud and Rose 2001) and following short distance displacements (<30 km) (Robichaud and Rose 2002a; Windle and Rose 2005). There is also indirect evidence of lek-like behaviour. Sex ratios change over the

spawning season, suggesting that males arrive first, followed by spawning females and immature cod (Lawson and Rose 2000b). Telemetric tracking of individual cod has indicated that males are more likely than females to remain within the general area of the grounds during the spawning season (Robichaud and Rose 2003). However, the locations of any lekking arenas on the Bar Haven grounds remain unknown.

In this study, I use fishing catch data and acoustic telemetry to investigate lekking arenas by examining spatial differences in the distribution of male and female cod over the Bar Haven spawning grounds. I test the following predictions of the lekking hypothesis: 1) cod will consistently form male-skewed aggregations during the spawning season; and 2) areas where male-skewed catches occur will have higher proportions of cod in spawning condition. The distribution of skewed and non-skewed fishing catches were examined with regard to temporal and spatial patterns, temperature and salinity. Acoustic telemetry techniques were used to study the movements of tagged cod and the distribution of individuals relative to male-skewed aggregations.

2.3 Materials and methods

2.3.1 Acoustic surveys

The study was conducted on the Bar Haven spawning ground, located among the inner islands of Placentia Bay, Newfoundland (Fig. 2.1). Bar Haven is the most consistently used spawning ground in the area (Lawson and Rose 2000b; Brattey and Healey 2003). From 1998 to 2000, acoustic surveys of the Bar Haven grounds were conducted from the RV Innovation, RV Mares (<14 m) and C.C.G.S. Shamook (25 m

research trawler) using a Biosonics single-beam DT4000 echosounder (38 kHZ, 6° half-power beam width, pulse durations 0.4 ms, 42 kHz digital sampling rate, pulse rate 2 pings s^{-1}), with the transducer mounted on a dead-weight body towed at 1.5 m depth. Acoustic surveys from 2001 to 2003 were conducted using the C.C.G.S. Shamook and employed a calibrated (Foote et al. 1987) Simrad EK500 split-beam echosounder (38 kHz, 6° half-power beam width, pulse duration 0.8 ms, 7 kHz digital sampling rate, pulse rate 1 ping s^{-1}), with the transducer mounted on a similar dead-weight body towed alongside the vessel at 1.5 m depth. Acoustic survey coverage of the spawning grounds and vicinity were similar in all years. Qualitative acoustic observations were also made in 2002 and 2003 during each tag survey using a 200 kHz Furuno echosounder on the SRV Gecho (7 m acoustic research vessel).

2.3.2 Fishing sets

Fishing sets were conducted from 1998 to 2003 at the Bar Haven grounds during the spawning season (Table 2.1, Fig. 2.2). In all years, cod aggregations located by acoustic surveys were fished using hand lines and feather hooks over a range of depths. Duration of fishing and numbers caught varied, ranging from a few minutes to half an hour and 13 to 152 fish per set. Cod were assessed for total length (TL), sex and weight. Maturity stages were determined through visual inspection of gonads, according to criteria described in Morrison (1990). Male cod were identified as either immature, in spawning condition, or spent. Males in spawning condition had testes that were full of milt, while spent gonads were stringy in appearance and had little or no remaining milt.

For females, individuals were classed as either immature, ripening, spawning or spent. Ripening ovaries had opaque, yellow-orange coloured eggs, while spawning ovaries had clear and hydrated eggs. Spent females had ovaries that were baggy in appearance and contained few or no eggs. Vertical profiles of water temperature and salinity were recorded near fishing sets using a Seabird CTD (Model SBE 19+).

2.3.3 Tagging

During early April 2002, aggregations of *G. morhua* were located acoustically near Woody Island in depths of 15 to 50 m and temperatures near 0 °C. On 14 April, individual cod were caught using hand lines and feather hooks. Fish of TL 58-60 cm and > 70 cm were placed in holding tanks. Smaller fish were released if in good condition. Sex of captive cod was determined by cannulation. Tagging was limited to cod that were in spawning condition, as determined by the presence of >50% hydrated eggs or milt in the cannula. A coded acoustic transmitter (Lotek Model CAFT16-2; 82 mm long x 16 mm diameter; 34.2 g in air, 18.1 g in water) was implanted in selected fish, and a t-bar anchor tag (Floy FD-68BC) was inserted into the musculature adjacent to the first dorsal fin to aid in visual identification. Tags with transmitter frequencies of 65.5 kHz were used for males and 76.8 kHz for females. Tagged fish were placed in a recovery tank and monitored up to 2 h for signs of stress, and only healthy fish were released as part of the study. A total of sixteen fish were released, comprising 4 small (58-60 cm) males and 4 large (≥ 70 cm) males, and 4 small females and 4 large females. All procedures were approved by the Animal Care Committee of Memorial University. A sentinel tag was

dropped to the ocean floor near the release site for tests of receiving distances. In April 2003, acoustic surveys located dense aggregations of cod near Bar Haven and Woody Islands. From these aggregations, a total of 9 spawning cod (4 males [65-66 cm] and 5 females [69-77 cm]) were tagged using similar equipment and procedures as in 2003.

2.3.4 Telemetry

Telemetric surveys for 2002 were initiated on 18 April over the last known location of the spawning aggregations, and were repeated on a daily basis until 2 May. Additional telemetric surveys in 2002 were conducted on 21 May and on 4, 5, 12 June. Surveys were conducted from the SRV Gecho outfitted with a 50 and 200 kHz Furuno echosounder, a sonar tag receiver (Lotek Model SRX-400) and an omnidirectional hydrophone (Lotek Model LHP-1). Based on the detection range of the sentinel tag and acoustic location of cod aggregations, a survey grid was established consisting of listening stations spaced 463 m apart and covering an area of approximately 25 km^2 (Fig. 2.3). During a survey, tag frequencies (65.5 kHz for males, 76.8 kHz for females) were monitored for 20 seconds at each station using the hydrophone and receiver. Once a tag was detected, additional listening stations were conducted in the vicinity and the position of the fish was estimated based on the strength of the acoustic signal. Previous tests of the receiving distance of the sentinel tag verified that the acoustic signal was strongest when listening directly above the known tag location. Position coordinates were recorded using an onboard NorthStar GPS (accuracy to 5 m).

During the 2003 spawning season, daily telemetric surveys were conducted from 8 April to 16 April inclusive, and 12 May to 16 May inclusive, in the same area, utilizing similar listening stations as well as additional sites identified by acoustic surveys. The distance between listening stations was reduced to 370 m, based on a slight deterioration in signal output from the sentinel tag.

In both 2002 and 2003 there were several occasions when adverse weather restricted coverage of the survey grid within a single day. When this occurred, listening stations over the non-surveyed portion of the grid were resumed at the earliest opportunity, typically the next day. On some occasions the survey grid was covered twice in one day (3 d in 2002 and 8 d in 2003).

2.3.5 Data analysis

Sex ratios within sampling sets were analysed using a binomial test, assuming a hypothetical proportion of 50% for each sex. Only fishing sets with > 10 fish were included in the analysis (n=42 sets). Two categories of fishing sets were derived from this test to form the basis of further analyses: those sets significantly skewed towards one sex (male- or female-skewed), and those with equal sex ratios (non-skewed).

A discriminant function analysis (DFA) was used to reveal which factors best distinguished skewed or non-skewed. Variables considered as predictors were fishing set coordinates (latitude and longitude, converted to decimal degrees), year, day of year, bottom depth, bottom temperature, and bottom salinity. A stepwise DFA was used to eliminate variables that did not significantly contribute to the model, using an inclusion

criteria of $\alpha = 0.05$ (SYSTAT, v. 11.0). Selected variables were then used in a robust quadratic DFA to classify fishing sets as either skewed or non-skewed. Cross-validation, whereby each case is classified by the functions derived from all cases other than that case, was used to determine error rates. Fishing sets were pooled into two groups (skewed vs. non-skewed), and bottom-associated depth, temperature and salinity, as well as mean length of cod were compared between groups using one-way ANOVA. Chi-square analysis was used to test for differences among skewed and non-skewed fishing sets in the observed proportions of maturity stages for males and females.

The geographical analysis of tagged cod distributions and fishing set data was accomplished using SPANS (TYDAC Research Inc., v. 7.1, 1999). The locations of fishing sets and the relocation coordinates for tagged cod were superimposed on maps of the Bar Haven spawning area, and were visually examined for patterns of distribution with reference to acoustic observations and geographic features. The distance (km) between consecutive relocation coordinates was measured for each tagged fish with two or more relocations. The minimum distance moved per individual fish was categorized as within-day ($0.5 \text{ h} < t < 10 \text{ h}$) or between consecutive survey dates ($10 \text{ h} < t < 30 \text{ h}$), where t indicates the time interval between consecutive relocations. Individuals with more than 30 h between relocations were not included in the analysis. Distances were averaged for each fish, grouped by sex, and compared using one-way ANOVA.

2.4 Results

2.4.1 Fishing sets

From 1998 to 2003, a total of 42 fishing sets were made at the Bar Haven grounds during the spawning season. Seven sets had significantly skewed sex ratios biased towards males (Table 2.1). Male-skewed sets were found in 5 of 6 survey years (1998 [n=1]; 1999 [n=3]; 2000 [n=1]; 2002 [n=1]; 2003 [n=1]). In four of the six years the only male-skewed sets occurred on the first sampling date of the year. Both sets in deep water (>100 m) caught more females than males, but no set was significantly biased towards females (Table 2.1).

The locations of male-skewed fishing sets from 4 separate survey years suggested some degree of spatial clustering on the spawning ground (Fig. 2.2). The results of the stepwise DFA indicated that longitude, latitude and year were the variables that best distinguished skewed and non-skewed fishing sets (Table 2.2). Discriminant functions derived from these variables accurately classified 100% of non-skewed sets and 71% of skewed sets, for an overall classification accuracy of 92.9% (Table 2.3). The cross-validation of the model revealed an error rate of 0% for non-skewed sets and 43% for skewed sets.

The mean total length (TL) of all cod in male-skewed sets was significantly higher than in non-skewed sets ($p < 0.001$; Table 2.4). This difference was significant for both males ($p < 0.001$) and females ($p < 0.001$). The TL of males and females differed significantly within non-skewed sets ($F = 12.07$, $df = 1$, $p = 0.001$), but this was not the case within male-skewed sets ($F = 3.07$, $df = 368$, $p = 0.08$).

There were notable differences in the maturity stages of cod in both types of fishing sets (Table 2.5). Male-skewed sets had a significantly higher proportion of spawning females ($p = 0.011$) and spent males ($p = 0.001$) compared to non-skewed sets, while non-skewed sets had a significantly higher proportion of immature males ($p < 0.001$) and spent females ($p = 0.033$)(Table 2.5). The proportions of immature females, ripening females, and spawning males did not differ significantly between set types.

The mean depth of male-skewed sets (32.0 ± 3.52 m)(mean ± S.E.) and non-skewed sets (38.5 ± 3.91 m) did not differ significantly ($F = 0.53$, $df = 1$, $p = 0.47$). Likewise, there were no significant differences between the mean bottom temperature of male-skewed sets (0.6 ± 0.35 °C) and non-skewed sets (0.1 ± 0.16°C) ($F = 1.44$, $df = 40$, $p = 0.24$), or the mean bottom salinity of male-skewed sets (32.2 ± 0.09) and non-skewed sets (32.3 ± 0.04) ($F = 0.95$, $df = 1$, $p = 0.34$). All male-skewed fishing sets were found at depths < 50 m, while non-skewed sets were found at depths ranging from 14 m to 125 m.

2.4.2 Tagged cod – group patterns

All 16 cod released in 2002 and 8 of 9 cod released in 2003 were relocated at least once on the spawning ground during telemetric surveys. Three of the 16 cod released in 2002 were also relocated in 2003. The relocation of tagged cod declined sharply towards the end of April 2002, matching a decline in acoustic observations of cod during the same telemetric surveys. Telemetric surveys in 2003 coincided with a high number of acoustic observations throughout April and early May.

In contrast to the distribution of male-skewed fishing sets, there were no clear patterns in the spatial distribution of tagged cod in either 2002 or 2003. There were no areas consistently dominated by relocations of either sex, and relocations of males were generally not associated with locations of male-skewed sets (Fig. 2.3). Of note, there appeared to be distinct spatial clustering of tagged fish on several occasions. However, the patterns were not consistent or maintained during the study.

2.4.3 Tagged cod – individual movements

A total of seven males (2 large, 5 small) and nine females (7 large, 2 small) were relocated on at least two consecutive survey dates. Multiple relocations were too infrequent to construct home ranges for each fish. Both males and females averaged approximately 3 relocations per individual, despite frequent telemetric surveys of the last known location of each fish. Individual cod that were relocated more than once were likely to be found in the same general area on consecutive survey dates. Males and females did not differ significantly in the mean distance moved between consecutive survey dates (males=0.57 ± 0.082 km, females=0.53 ± 0.099 km; $F = 0.12$, $df = 1$, $p = 0.73$). Likewise, there was no significant difference in the mean distance moved between large (0.51 ± 0.107 km) and small cod (0.66 ± 0.158 km) between survey days ($F = 0.94$, $df = 1$, $p = 0.35$).

A total of eight males (3 large, 5 small) and seven females (6 large, 1 small) were relocated multiple times within a single day. The mean within-day movement of males between consecutive relocations (1.2 ± 0.38 km) was greater than for females (0.3 ± 0.09

km), but not significantly ($F = 4.31$, $df = 1$, $p = 0.058$). Mean within-day movements of large males and females were 1.05 ± 0.68 km and 0.34 ± 0.11 km, respectively. Mean within-day movement for small males was 1.27 ± 0.5 km, while the within-day distance moved by the single small female was approximately 0.21 km. Several males were relocated over 2 km from their last known position within a three-hour period (Fig. 2.4).

The distance moved between consecutive survey days and the time interval between relocations (Fig. 2.4) was not significantly correlated for males ($R^2 = 0.041$, $F = 0.34$, $p = 0.58$) or females ($R^2 = 0.070$, $F = 1.13$, $p = 0.31$). For all within-day relocations, the distance and time duration between consecutive relocations was not correlated for males ($R^2 = 0.001$, $F = 0.010$, $p = 0.92$) or females ($R^2 = 0.074$, $F = 1.44$, $p = 0.25$).

2.5 Discussion

Fishing set data indicated the presence of male dominated aggregations in 5 of 6 spawning seasons studied at the Bar Haven grounds. A trend in the temporal distribution of sex-biased catches was evident, as male-skewed fishing sets were only found at or near the earliest April survey date in each year. These results were consistent with previous studies in Newfoundland and adjacent waters that have also noted male-skewed catches early in the spawning season (McKenzie 1940; Morgan and Trippel 1996; Lawson and Rose 2000b). In the present study it is unclear whether the skewed sex ratios were due to the earlier arrival of males to the spawning grounds or to a segregated distribution of sexes. The approximate date on which cod aggregations arrived to the spawning grounds was not determined for each year, and furthermore, females in spawning condition were

also found early in the spawning season. The co-occurrence of non-skewed and male-skewed catches may indicate that both sexes arrive to the Bar Haven grounds concurrently, but that the sexes maintain some degree of spatial separation that is more apparent early in the spawning season. This might be expected if male cod establish spawning sites and female cod are distributed peripherally to these sites until they move in to spawn, as suggested by the behaviour of cod in captive studies (Brawn 1961a; Hutchings et al. 1999). The establishment of spawning grounds by male cod is supported by studies that have noted the presence of male-skewed catches throughout the spawning season (Morgan and Trippel 1996; Nordeide 1998; Lawson and Rose 2000b), as well as the higher relocation rate of tagged males over the grounds (Robichaud and Rose 2003).

A depth-related pattern was evident in the spatial distribution of male-skewed sets over the Bar Haven grounds. Male-skewed sets were consistently located at shallower depths (<50 m), while females were relatively more numerous in the few deeper water fishing sets. Aggregations with equal sex ratios did not appear to follow any pattern, and were taken at all sampling depths ranging from 14 m -125 m. The depth distribution of male-skewed fishing sets was supported by telemetric tracking of tagged cod, which revealed that males mostly confined their movements to shallower waters. Interestingly, Morgan and Trippel (1996) noted a similar trend in the depth distribution of sex-skewed catches on the Grand Banks, and suggested that female cod might remain in deeper, warmer waters before moving on to the shelf slopes to spawn. It is unclear whether this behaviour would apply in the case of the shallow Bar Haven grounds, as water temperature profiles are relatively uniform early in the year and warmer waters occur

near the surface. Given that non-skewed sets were distributed at a wide range of depths, the current results suggest that the hypothesized movement of females into male dominated aggregations involves both horizontal and vertical migrations in the context of a shallow spawning ground.

Concurrent echosounding and hand line sampling over the full range of depths of the fish revealed no consistent layering of cod at the sites of either male-skewed or non-skewed sets. Any structuring observed was in vertical "columns" in which no sex differences could be determined. These observations do not support the contentions of Hutchings et al. (1999), who suggested that vertical structuring of females above males might account for male dominated catches and higher proportions of spawning females in bottom trawl surveys, as reported by Morgan and Trippel (1996).

The location of male-skewed sets on the spawning ground was not consistent between years, although skewed sets from 4 of 6 survey years were found within a 1.3 km^2 area southwest of Little Woody Island. Interestingly, non-skewed sets were not found in this immediate area. DFA modeling was able to successfully classify 71% of male-skewed sets and 100% of non-skewed sets using spatial coordinates and sampling year variables. The relatively high classification error rate of 43% for male-skewed sets is likely due to the two male-skewed outliers positioned southeast of the main grouping. In 1999 male-skewed sets were taken from sites separated by approximately 2 km, and suggest the presence of multiple concurrent lekking sites as seen in other teleost species (McKaye 1983; Figenschou et al. 2004). These results suggest that male cod do not consistently aggregate near a specific landmark on the spawning ground, but rather that

males favour shallower depths. This may explain why the majority of male-skewed sets were taken from the western portion of the spawning ground, as this area includes a large proportion of the available shallow habitat.

Catch compositions within and outside male dominated aggregations were consistent with a lekking mating system. Male-skewed fishing sets had higher proportions of spawning females compared to non-skewed sets, suggesting that male dominated aggregations are consistently important in terms of spawning activity at the Bar Haven grounds. In contrast, non-skewed sets distributed peripherally to male-skewed sets had higher proportions of immature males and spent females. These observations provide supporting small-scale field evidence for the laboratory work of Brawn (1961a) and Hutchings et al. (1999), who noted that dominant males establish territories during the spawning season that are spatially segregated from females and immature cod, and that females briefly enter these territories to spawn and then return to peripheral locations. The higher proportion of spawning females in male-skewed sets was also consistent with reported fishing data from the Grand Banks (Morgan and Trippel, 1996), and suggests sex-specific consistencies in the spawning behaviour of cod at small and large scales in the north-west Atlantic. In the present study it was unclear why the proportion of spawning males was not greater in skewed sets. This may indicate that spawning males are widely distributed across the Bar Haven grounds.

There was also some evidence of size-assortative mating (Hutchings and Myers, 1993), as both males and females in male-skewed sets were significantly larger than in non-skewed sets. The spawning behaviour of cod favours assortative mating, as large

male cod attempting to mate with smaller females experience reduced reproductive success (Rakitin et al., 2001; Bekkevold et al., 2002); possibly as a result of the reduced alignment of genital pores during the ventral mount (Hutchings et al., 1999). In the present study the association between larger cod and spawning activity is worthy of note, as captive male cod have been found to form size-based dominance hierarchies during the spawning season, within which spawning success may be skewed towards the largest, most aggressive males (Brawn, 1961a; Hutchings et al., 1999; Bekkevold et al., 2002). Skewed reproductive success towards larger, more dominant males is also a characteristic of lekking mating systems (Höglund and Alatalo, 1995). While spatial sorting by size has previously been reported in both spawning and over-wintering aggregations of cod (Rose, 1993; Hutchings and Myers, 1993; Nordeide, 1998; Rose, 2003), this study reports for the first time a linkage between male-skewed catches, spawning activity, and size distributions at small scales in the north-west Atlantic.

It is important to note that the remotely monitored movements of tagged cod cannot be directly related to possible lekking activities without visual confirmation of behaviour or spawning status at the time of each relocation. Therefore, the movements of individual cod should be interpreted with caution. The telemetric relocations of tagged cod revealed no specific areas of the spawning ground that were used with more frequency by either sex, nor any stable clustering of tagged male cod. Moreover, relocations of tagged male cod were not confined to areas where male dominated fishing sets were found. On average, males and females did not differ in their movements during or between survey days. Distances ranged by male cod were in some cases over 2 km

within a few hours. In a study of cod spawning behaviour at Bar Haven, Robichaud and Rose (2003) reported that tagged males had significantly higher relocation rates than females, although males were not always relocated on consecutive surveys. Furthermore, high turnover rates of spawning cod have previously been described in the area (Robichaud and Rose, 2002b). In combination with the present study, these results suggest that cod may be highly mobile on the spawning ground. The movement of individuals within a lekking system is not unexpected. Females may periodically enter and leave male territories, while males may move between lekking sites or display for limited periods (Höglund and Alatalo, 1995). Intermittent lekking, where males occupy a lek for only part of the day, may be common when, as it is in cod, males are not required to protect the spawn and do not have an energetic investment in nest construction (Loiselle and Barlow, 1978). Diel patterns in the spawning activity of captive cod (Brawn 1961a; Kjesbu 1989; Hutchings et al. 1999) may indicate that males only display at leks during the evening, although this is not well understood. Cod may also be expected to move over the spawning ground if they are fixed relative to each other rather than landmarks (Höglund and Alatalo, 1995). In this case, male territories may encompass a moveable "zone" around each individual (Brawn 1961b). Cod are known to consume a variety of prey items during the spawning season (Mello and Rose 2005b), suggesting that the movements of tagged cod may also be related to feeding activities.

In summary, the recurring linkage between male-skewed catches and female spawning activity is indicative of a lekking arena at the Bar Haven grounds. Males appear to prefer shallower depths but are not fixed to any landmarks. A comprehensive

analysis of bottom types in the area may reveal the extent to which habitat quality varies with depth and location. The movements of tagged cod suggest that individuals are highly mobile throughout the spawning season, although it is unclear whether such behaviours form part of lekking activities. It should be noted that this study was conducted at one small spawning ground, and that cod spawning behaviours at other locations and at larger scales may differ from these observations. Nevertheless, these results are consistent with previous studies in the north-west Atlantic and provide additional field evidence in support of the cod lekking hypothesis (Hutchings et al. 1999; Nordeide and Folstad 2000).

Table 2.1 Sampling period, number of fishing sets per year, and catch data for significantly male-skewed fishing sets (date, depth, *N*, sex ratio) taken at the Bar Haven spawning grounds from 1998 to 2003.

			Male-Skewed Sets				
Year	**Sample Period**	**# Sets**	**Date**	**Depth (m)**	***N***	**Sex Ratio (F:M)**	**p-value (Binomial test)**
1998	18 Apr - 1 Jul	6	18 Apr	48	129	0.04:1	< 0.001
1999	7 Apr - 4 May	12	8, 9, 13 Apr	24, 35, 38	28, 20, 67	0.17:1, 0.11:1, 0.34:1	<0.001, <0.001, <0.001
2000	3 Apr - 21 May	3	3 Apr	30	54	0.54:1	0.041
2001	6 Apr - 12 Apr	3	None	--	--	--	--
2002	7 Apr - 11 Apr	5	7 Apr	20	22	0.22:1	0.004
2003	3 Apr - 15 Apr	13	3 Apr	29	50	0.43:1	0.007

Table 2.2 Results from stepwise discriminant function analysis predicting skewness of sex ratios of fishing sets conducted on Bar Haven spawning grounds, 1998-2003. Variables shown are those remaining in the model after stepwise selection.

Step	Variable Entered	Variable Removed	Number In	Wilks' Lamda	F statistic	*P*
1	Longitude		1	0.903	4.287	.045
2	Latitude		2	0.788	5.238	.010
3	Year		3	0.696	5.521	.003

Table 2.3 Results of discriminant function analysis of fishing sets of known and cross-validated sex ratios, using variables longitude, latitude, and year. Values in bold are percentages of fish correctly classified. Sample sizes (*N*) in parentheses.

	Predicted		
	Equal sex ratio	Male-dominated	Total
Known[a]			
Equal sex ratio	**100**	0	100
	(35)	(0)	(35)
Male-dominated	29	**71**	100
	(2)	(5)	(7)
Cross-validated[b]			
Equal sex ratio	**100**	0	100
	(35)	(0)	(35)
Male-dominated	43	**57**	100
	(3)	(4)	(7)

[a] 95.2% of original grouped cases correctly classified
[b] 92.9% of cross-validated grouped cases correctly classified

Table 2.4 Results of one-way ANOVA comparing mean total length (cm) measurements of cod in male-dominated and equal sex ratio fishing sets.

Category	N	Mean TL (± S.E.)	ANOVA df	ANOVA F	ANOVA p
All Cod					
Male Dominated	370	65.6 ± 0.58	1	257.93	<0.001
Equal sex ratio	1638	57.5 ± 0.20			
Males					
Male Dominated	304	65.2 ± 0.59	1	227.34	<0.001
Equal sex ratio	842	56.9 ± 0.26			
Females					
Male Dominated	66	67.8 ± 1.80	1	63.44	<0.001
Equal sex ratio	795	58.2 ± 0.31			

Table 2.5 Chi-square analysis comparing proportions of immature males, immature females, ripening females, males in spawning condition, females in spawning condition, spent males, and spent females between male-skewed and equal sex ratio fishing sets.

Variable	df	χ^2	*P*
Immature males*	1	16.291	<0.001
Immature females	1	1.635	0.201
Ripe females	1	0.221	0.638
Spawning males	1	0.102	0.750
Spawning females**	1	6.437	0.011
Spent males**	1	11.609	0.001
Spent females*	1	4.524	0.033

*significantly greater proportion in non-skewed sets
**significantly greater proportion in male-skewed sets

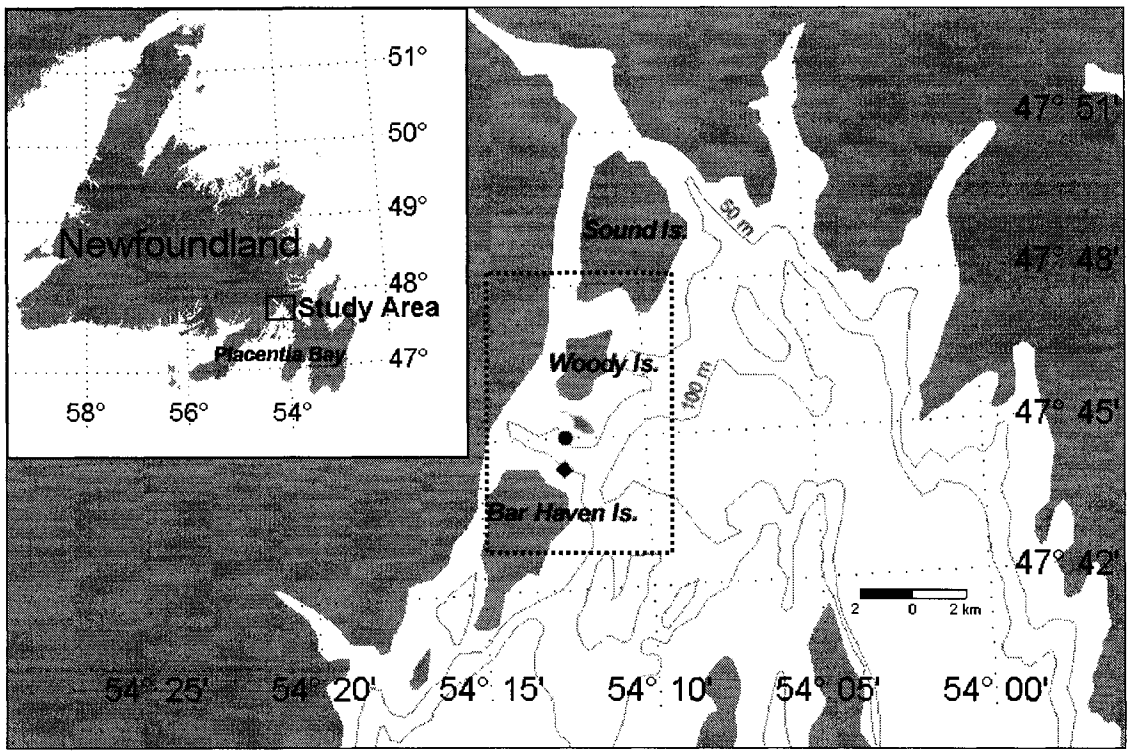

Figure 2.1 Inner islands of Placentia Bay, Newfoundland, showing main area of cod spawning activity near Bar Haven Island (dotted square), tagged cod release locations in 2002 (n=16; circle) and 2003 (n=9; diamond). Inset: island of Newfoundland, with location of study area.

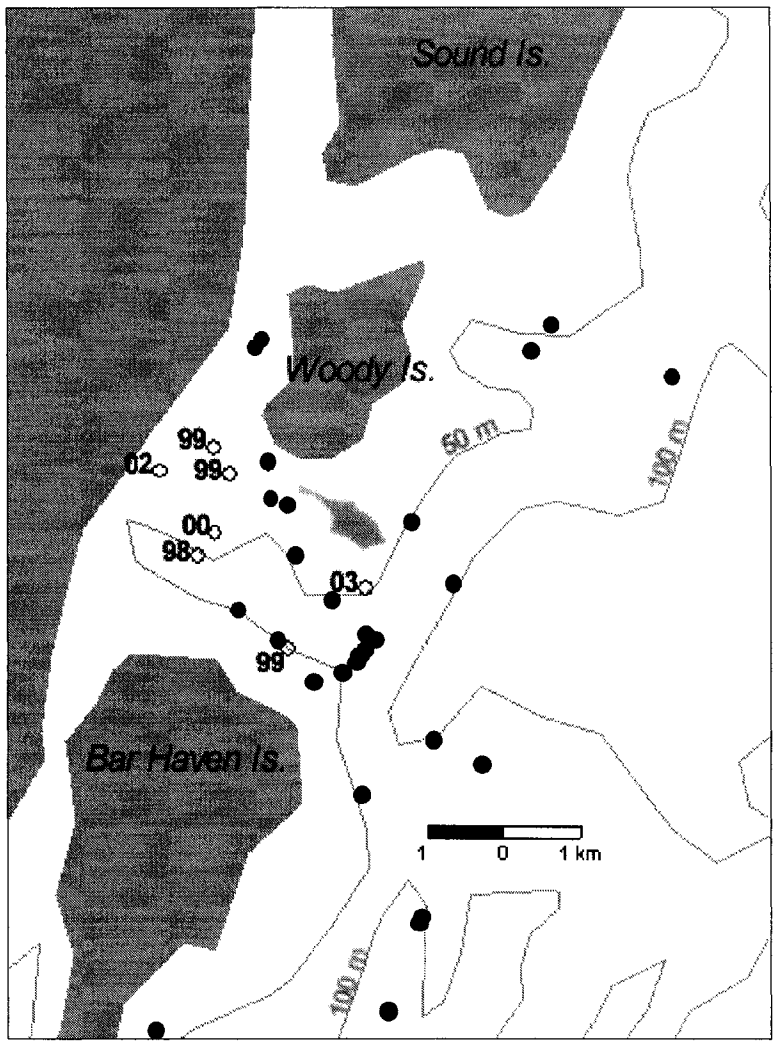

Figure 2.2 The spatial distribution of male-skewed (open circles, n = 7) and non-skewed (closed circles, n = 35) fishing sets taken over the Bar Haven spawning grounds from 1998-2003. Sampling years of male-skewed sets are indicated by a two-digit code.

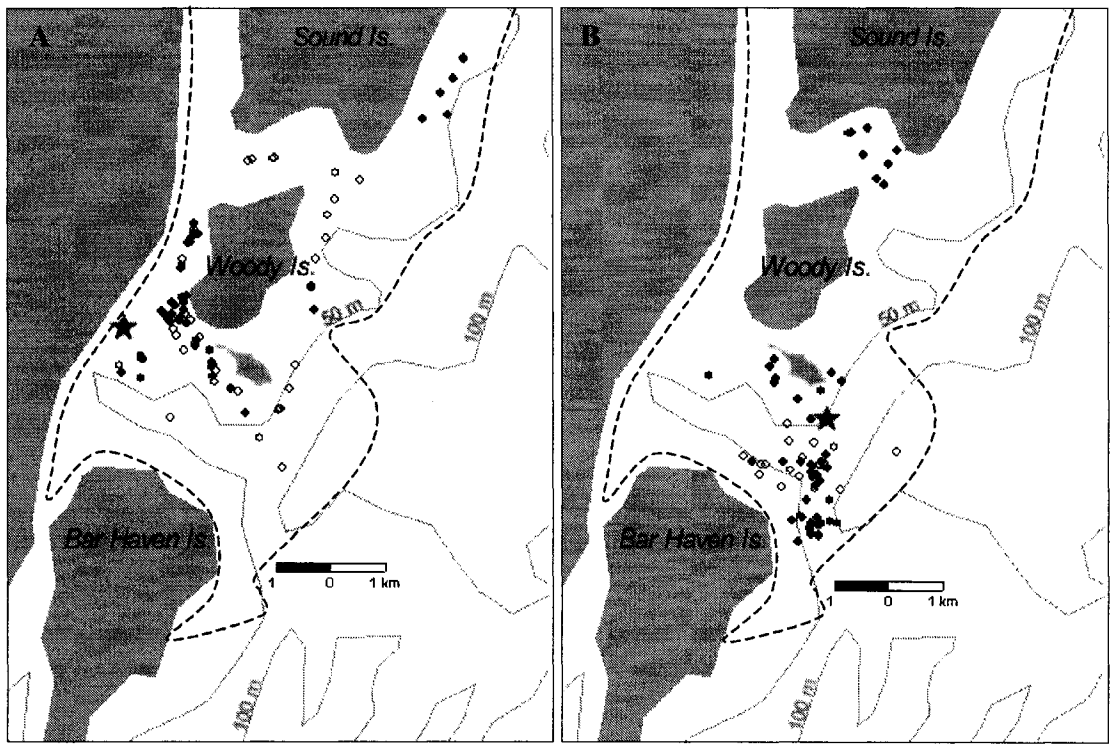

Figure 2.3 Cumulative distribution of relocation coordinates for male (open circles) and female (closed circles) tagged cod in a) 2002 and b) 2003. The area within the dashed line indicates approximate survey coverage of the spawning grounds. Male-skewed sets found within each year of telemetry surveys are indicated by stars.

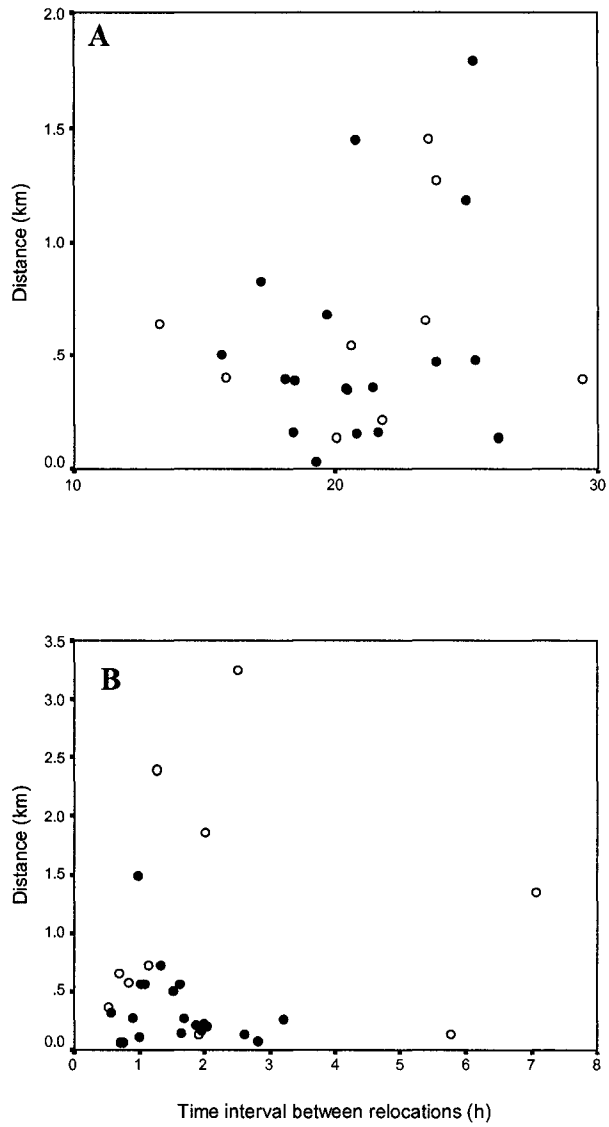

Figure 2.4 Relationship between time and the minimum distance moved between successive relocations for male (open circles) and female (closed circles) cod located on a) back-to-back survey days and b) within-day surveys of the Bar Haven spawning ground.

SUMMARY

In this thesis the hypothesis is directly tested for the first time that spatial familiarity is important to the successful homing of cod over short distances. It was found that large (>70 cm) and small (58-60 cm) sizes of cod that were transplanted from a coastal spawning ground homed more successfully from a site in their traditional migratory pathway than from a site in the opposing direction, supporting the hypothesis that cod use familiar spatial features to navigate. Males and smaller fish were more successful at homing compared to females and larger cod, although the small sample sizes require caution in interpreting the results. Navigation by olfactory clues was an unlikely explanation for the homing results, as the release site in the migratory pathway was upcurrent of the spawning ground. Although it is unlikely that the higher returns from this site were due to passive transport, cod transplanted to the migratory pathway may have actively used prevailing currents to return to the spawning ground. The higher homing rates of smaller cod were not expected, as it was hypothesized that larger, multi-year spawners would have superior homing success given that they likely had more experience with travelling the traditional migratory route in Placentia Bay. The results suggest that the learning of migration routes occurs in years prior to first-spawning and at smaller size classes of fish than were tagged, and support the hypothesis that immature cod learn spatial information while accompanying migrations of older spawning cod (Rose, 1993). These results have potential implications for the recovery of collapsed cod populations, as the resumption of traditional migratory behaviours may require spatial

learning and social transmission of routes from more experienced individuals that have largely been removed through fishing activities.

The recently posed hypothesis that cod employ a lekking mating system is based largely on observations from laboratory studies, as well as fishing data collected over large geographic areas (Hutchings et al., 1999; Nordeide and Folstad, 2000). This work is the first to combine fishing catches and acoustic telemetry in order to locate possible lekking arenas used by wild cod at a small-scale spawning ground. Consistent patterns were found in the temporal and spatial distributions of male and female cod using fishing data collected during the 1999-2003 spawning seasons at the Bar Haven grounds. Male-dominated aggregations were observed in early to mid-April in five of six survey years, and were found consistently within a specific area of the Bar Haven grounds and exclusively at depths less that 50 m. The proportion of spawning females was significantly higher in male-skewed fishing sets, suggesting that areas where male dominated catches occur are consistently important in terms of spawning activity. The relative spatial distribution and maturity stages of cod within male-skewed and non-skewed was consistent with Grand Banks data reported by Morgan and Trippel (1996), and suggested that female cod remain spatially segregated from mature males until they enter male territories to spawn. Evidence for size-assortative mating was found, as male-skewed sets were composed of larger cod compared to non-skewed sets. The association between large cod and higher proportions of spawning females supported previous work that reported the establishment of male dominance hierarchies within which spawning was skewed towards larger individuals. Cod that were acoustically tagged and released at

the grounds in 2002 and 2003 did not display any sex-specific spatial patterns of distribution, nor were tagged males confined to areas where male-dominated fishing sets were consistently found. Telemetric relocations within and between survey days suggested that cod are highly mobile over the spawning grounds. Overall, the results of this study were consistent with a traditional lekking arena on the Bar Haven spawning grounds. Future work is required to determine whether differences exist in the vertical distribution of wild-living male and female cod, and to examine trends in the spatial and temporal distributions of leks at other known spawning grounds.

REFERENCES

Arnold, G. P., Greer, W. M., Emerson, L. S., and Holford, B. H. 1994. Movements of cod (*Gadus morhua* L.) in relation to the tidal streams in the southern North Sea. ICES Journal of Marine Science 51: 207-232.

Aronson, L. R. 1971. Further studies on orientation and jumping behaviour in the Gobiid fish, *Bathygobius soporator*. Annals of the New York Academy of Sciences 188: 378-392.

Bagge, O., Thurow, F., Steffensen, E., and Jesper, B. 1994. The Baltic cod. Dana 10:1-28.

Bekkevold, D., Hansen, M.M., and Loeschck, V. 2002. Male reproductive competition in spawning aggregations of cod (*Gadus morhua*, L.). Molecular Ecology 11: 91-102.

Bergstad, O. A., Jorgensen, T., and Dragesund, O. 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fisheries Research 5: 119-161.

Bradbury, I.R., Snelgrove, P.V.R., and Fraser, S. 2000. Transport and development of eggs and larvae of Atlantic cod, *Gadus morhua*, in relation to spawning time and location in coastal Newfoundland. Canadian Journal of Fisheries and Aquatic Sciences 57: 1761-1772.

Braithwaite, V. A. 1998. Spatial memory, landmark use and orientation in fish. In: Spatial Representation in Animals (Sue Healy, ed.), pp. 86-102. Oxford University Press, Oxford.

Brander, K. 1994. (Ed.) Spawning and life history information for North Atlantic cod stocks. ICES Cooperative Research Report 205: 150 pp.

Brattey, J., Porter, D. R., and George, C. W. 2002. Exploitation rates and movements of Atlantic cod (*Gadus morhua*) in NAFO Subdivision 3Ps based on tagging experiments conducted during 1997-2001. Canadian Science Advisory Secretariat Research Documents 2002/003.

Brattey, J., and Healey, B. 2003. Updated estimates of exploitation from tagging of Atlantic cod (*Gadus morhua*) in NAFO Subdivision 3Ps during 1997-2003. Canadian Science Advisory Secretariat Document 2003/091.

Brawn, V.M. 1961a. Reproductive behaviour of the cod (*Gadus callarias* L.). Behaviour 18: 177-197.

Brawn, V.M. 1961b. Aggressive behaviour in the cod (*Gadus callarias* L.). Behaviour 18: 107-147.

Chambers, R. C., and Waiwood, K. G. 1996. Maternal and seasonal differences in egg sizes and spawning characteristics of captive Atlantic cod, *Gadus morhua*. Canadian Journal of Fisheries and Aquatic Sciences 53: 1986-2003.

Comeau, L. A., Campana, S. E., and Castonguay, M. 2002a. Automated monitoring of a large-scale cod (*Gadus morhua*) migration in the open sea. Canadian Journal of Fisheries and Aquatic Sciences 59: 1845-1850.

Comeau, L. A., Campana, S. E., and Chouinard, G. A. 2002b. Timing of Atlantic cod (*Gadus morhua* L.) seasonal migrations in the southern Gulf of St. Lawrence: interannual variability and proximate control. ICES Journal of Marine Science 59: 333-351.

Corten, A. 2002. The role of "conservatism" in herring migrations. Reviews in Fish Biology and Fisheries 11: 339-361.

Dodson, J. J. 1988. The nature and role of learning in the orientation and migratory behavior of fishes. Environmental Biology of Fishes 23: 161-182.

Donaldson, T.J. 1995. Courtship and spawning of nine species of wrasses (Labridae) from the western Pacific. Japanese Journal of Ichthyology 42: 311-319.

Engen, F., and Folstad, I. 1999. Cod courtship and song: a song at the expense of dance? Canadian Journal of Zoology 77: 542-550.

Figenschou, L., Folstad, I., and Liljedal, S. 2004. Lek fidelity of male Arctic charr. Canadian Journal of Zoology 82: 1278-1284.

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., and Simmonds, E.J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report No. 144

Gladstone, W. 1994. Lek-like spawning, parental care and mating periodicity of the triggerfish *Pseudobalistes flavimarginatus* (Balistidae). Environmental Biology of Fishes 39: 249-257.

Godø, O. R. 1984. Migration, mingling and homing of north-east Arctic cod from two separated spawning grounds. In: Reproduction and recruitment of Arctic cod (Godø, O. R., and Tilseth, S., eds.), pp. 289-302. Bergen: Institute of Marine Research.

Godø, O. R. 1995. Transplantation-tagging-experiments in preliminary studies of migration of cod off Norway. ICES Journal of Marine Science 52: 955-962.

Green, J. M., and Wroblewski, J. S. 2000. Movement patterns of Atlantic cod in Gilbert Bay, Labrador: evidence for bay residency and spawning site fidelity. Journal of the Marine Biological Association of the United Kingdom 80: 1077-1085.

Harden-Jones, F. R. (1968). Fish migration. London: Edward Arnold Publishers Ltd.

Hasler, A. D., and Scholz, A. T. 1983. Olfactory Imprinting and Homing in Salmon. Springer-Verlag, Berlin.

Helfman, G. S., and Schultz, E. T. 1984. Social transmission of behavioral traditions in a coral reef fish. Animal Behaviour 32: 379-384.

Höglund, J., and Alatalo, R.V. 1995. Leks. Princeton University Press, Princeton.

Hunter, E., Metcalfe, J. D., and Reynolds, J. D. 2003. Migration route and spawning area fidelity by North Sea plaice. Proceedings of the Royal Society, Series B: Biological Sciences 270: 2097-2103.

Hutchings, J. A., Myers, R. A., and Lilly, G. R. 1993. Geographic variation in the spawning of Atlantic cod, *Gadus morhua*, in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 50: 2457-2467.

Hutchings, J.A., Bishop, T.D., and McGregor-Shaw, C.R. 1999. Spawning behaviour of Atlantic cod, *Gadus morhua*: evidence of mate competition and mate choice in a broadcast spawner. Canadian Journal of Fisheries and Aquatic Sciences 56: 97-104.

Kaunda-Arara, B., and Rose, G. A. 2004. Homing and site fidelity in the greasy grouper *Epinephelus tauvina* (Serranidae) within a marine protected area in coastal Kenya. Marine Ecology-Progress Series 277: 245-251.

Kjesbu, O. 1989. The spawning activity of cod, *Gadus morhua* L. Journal of Fish Biology 41: 613-618.

Kulka, D. W., Wroblewski, J. S., and Narayanan, S. 1995. Recent changes in the winter distribution and movements of northern Atlantic cod (*Gadus morhua* Linnaeus, 1758) on the Newfoundland-Labrador Shelf. ICES Journal of Marine Science 52: 889-902.

Lawson, G. L., Rose, G. A., and Brattey, J. 1998. Movement patterns of inshore cod in Subdivision 3Ps (southern Newfoundland) based on marked-recapture studies during 1996-97. Canadian Stock Assessment Secretariat Research Document 98/24.

Lawson, G. L., and Rose, G. A. 2000a. Seasonal distribution and movements of coastal cod (*Gadus morhua* L.) in Placentia Bay, Newfoundland. Fisheries Research 49: 61-75.

Lawson, G. L. and Rose, G. A. 2000b. Small-scale spatial and temporal patterns in spawning of Atlantic cod (*Gadus morhua*) in coastal Newfoundland waters. Canadian Journal of Fisheries and Aquatic Sciences 57: 1011-1024.

Lear, W.H., and Parsons, L.S. 1993. History and management of the fishery for northern cod in NAFO divisions 2J, 3K and 3L. In: Perspectives on Canadian marine fisheries management. (Parsons L.S., and Lear W.H.). Canadian Bulletin of Fisheries and Aquatic Sciences 226: 55-90.

Lilly, G. R., Murphy, E. F., Healey, B. P., Maddock Parsons, D., and Stead, R. 2004. An update of the status of the cod (*Gadus morhua*) stock in NAFO Divisions 2J+3KL in March 2004. Canadian Science Advisory Secretariat Research Document 2004/023.

Loiselle, P.V., and Barlow, G.W. 1978. Do fishes lek like birds? In: Contrasts in behaviour: adaptations in the aquatic and terrestrial environments (Reese E.S., and Lighter F.J., eds.), pp. 31-76. Wiley, New York.

Mazeroll, A.I., and Montgomery, W.L. 1998. Daily migrations of a coral reef fish in the Red Sea (Gulf of Aqaba, Isreal): initiation and orientation. Copeia 4: 893-905.

McKaye, K.R. 1983. Ecology and breeding behavior of a cichlid fish, *Cyrtocara eucinostomus*, on a large lek in Lake Malawi, Africa. Environmental Biology of Fishes 8: 81-96.

McKenzie, R.A. 1940. Nova Scotian autumn cod spawning. Journal of the Fisheries Research Board of Canada 5: 105-120.

McQuinn, I. H. 1997. Metapopulations and the Atlantic herring. Reviews in Fish Biology and Fisheries 7: 297-329.

Mello, L.G.S., and Rose, G. A. 2005a. Seasonal variation in abundance and stock composition of Atlantic cod (*Gadus morhua*) in Placentia Bay, Newfoundland in relation to fisheries. Fisheries Research 74: 142-156.

Mello, L.G.S., and Rose, G.A. 2005b. Seasonal growth of Atlantic cod: effects of temperature, feeding and reproduction. Journal of Fish Biology 67: 149-170.

Morgan, M.J., and Trippel, E.A. 1996. Skewed sex ratios in spawning shoals of Atlantic cod (*Gadus morhua*). ICES Journal of Marine Science 53: 820-826.

Morrison, C.M. 1990. Histology of the Atlantic cod, *Gadus morhua*: an atlas. Part 3. Reproductive tract. Canadian Special Publication of Fisheries and Aquatic Sciences No. 110.

Nordeide, J.T. 1998. Coastal cod and north-east Arctic cod – do they mingle at the spawning grounds in Lofoten? Sarsia 83: 373-379.

Nordeide, J.T., and Kjellsby, E. 1999. Sound from spawning cod at their spawning grounds. ICES Journal of Marine Science 56: 326-332.

Nordeide, J.T., and Folstad, I. 2000. Is cod lekking or a promiscuous group spawning? Fish and Fisheries 1: 90-93.

Otterlind, G. 1985. Cod migration and transplantation experiments in the Baltic. Journal of Applied Ichthyology 1: 3-16.

Odling-Smee, L., and Braithwaite, V.A. 2003. The role of learning in fish orientation. Fish and Fisheries 4: 235-246.

Quinn, T. P., and Dittman, A. H. 1990. Pacific salmon migrations and homing: mechanisms and adaptive significance. Trends in Ecology and Evolution 5:174-177.

Rakitin, A., Ferguson, M. M., and Trippel, E. A. 1999. Sperm competition and fertilization success in Atlantic cod (*Gadus morhua*): effect of sire size and condition factor on gamete quality. Canadian Journal of Fisheries and Aquatic Sciences 56: 2315-2323.

Reese, E. S. 1989. Orientation behaviour of butterflyfishes (family Chaetodontidae) on coral reefs: spatial learning or route specific landmarks and cognitive maps. Environmental Biology of Fishes 25: 79-86.

Robichaud, D., and Rose, G. A. 2001. Multiyear homing of Atlantic cod to a spawning ground. Canadian Journal of Fisheries and Aquatic Sciences 58: 2325-2329.

Robichaud, D. and Rose, G. A. 2002a. The return of cod transplanted from a spawning ground in southern Newfoundland. ICES Journal of Marine Science 59: 1285-1293.

Robichaud, D. and Rose, G. A. 2002b. Assessing evacuation rates and spawning abundance of marine fishes using coupled telemetric and acoustic surveys. ICES Journal of Marine Science 59: 254-260.

Robichaud, D., and Rose, G. A. 2003. Sex differences in cod residency on a spawning ground. Fisheries Research 60: 33-43.

Robichaud, D., and Rose, G. A. 2004. Migratory behaviour and range in Atlantic cod: inference from a century of tagging. Fish and Fisheries 5: 185-214.

Rose, G. A. 1993. Cod spawning on a migration highway in the north-west Atlantic. Nature 366: 458-461.

Rose, G. A. 2003. Monitoring coastal Northern cod: towards an optimal survey of Smith Sound, Newfoundland. ICES Journal of Marine Science 60: 453-462.

Rose, G.A., deYoung, B., and Colbourne, E. B. 1995. Cod (*Gadus morhua*) migration speeds and transport relative to currents on the north-east Newfoundland Shelf. ICES Journal of Marine Science 52: 903-914.

Rowe, S., and Hutchings, J.A. 2003. Mating systems and the conservation of commercially exploited marine fish. Trends in Ecology and Evolution 18: 567-572.

Rowe, S., and Hutchings, J.A. 2004. The function of sound production by Atlantic cod as inferred from patterns of variation inn drumming muscle mass. Canadian Journal of Zoology 82: 1391-1398.

Sand, O., and Karlsen, H. E. 1986. Detection of infrasound by the Atlantic cod. Journal of Experimental Biology 125: 197-204.

Scott, W. B., and Scott, M.G. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Science 219: 731 pp.

Smedbol, R. K. and Wroblewski, J. S. 1997. Evidence for inshore spawning of northern Atlantic cod (*Gadus morhua*) in Trinity Bay, Newfoundland, 1991-1993. Canadian Journal of Fisheries and Aquatic Sciences 54: 177-186.

Smedbol, R. K., and Wroblewski, J. S. 2002. Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population. Fisheries Research 55: 161-174.

Stensholt, B. K. 2001. Cod migration patterns in relation to temperature: analysis of storage tag data. ICES Journal of Marine Science 58: 770-793.

Templeman, W. 1965. Some instances of cod and haddock behaviour and concentrations in the Newfoundland and Labrador areas in relation to food. ICNAF Special Publication 6: 449-461.

Templeman, W. 1966. Marine resources of Newfoundland. Fisheries Research Board of Canada, Bulletin 154.

Templeman, W. 1974. Migrations and intermingling of Atlantic cod (*Gadus morhua*) stocks of the Newfoundland area. Journal of Fisheries Research Board of Canada 31: 1073-1092.

Waburton, K. 1990. The use of local landmarks by foraging goldfish. Animal Behaviour 40: 203-215.

Wedekind, C. 1996. Lek-like spawning behaviour and different female mate preferences in roach (Rutilus rutilus). Behaviour 133: 681-695.

Windle M.J.S., and Rose, G.A. 2005. Migration route familiarity and homing of transplanted cod (*Gadus morhua*). Fisheries Research 75: 193-199.

Wroblewski, J. S., Nolan, B.G., Rose, G.A., and deYoung, B. 2000. Response of individual shoaling Atlantic cod to ocean currents on the northeast Newfoundland shelf. Fisheries Research 45: 51-59.

APPENDICES

APPENDIX 1 – Observation data for cod tagged at the Bar Haven grounds in April 2002.

OBSERVATION SHEET

ID	Date of Capture	Time of Surgery	External Tag #	Code	Freq.	Length (cm)	Sex	Maturity	Weight (kg)	Catch Location			Release Location				Time of Release
										Lat.	Long.	Depth	Area	Lat.	Long.	Depth	
1	April 12/02	10:15	H71401	7	65.5	76	M	MatP	4.08	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
2	April 12/02	10:24	H71484	32	76.8	71	F	MatA	3.22	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
3	April 12/02	10:35	H71485	31	76.8	72	F	MatA	2.78	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
4	April 12/02	10:46	H71486	35	76.8	77	F	MatA	4.6	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
5	April 12/02	10:56	H71487	34	76.8	85	F	MatA	5.87	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
6	April 12/02	11:02	H71402	38	65.5	80	M	MatP	4.4	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
7	April 12/02	11:12	H71403	32	65.5	76	M	P Spent	4.31	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
8	April 12/02	11:20	H71489	36	76.8	71	F	MatA	2.97	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
9	April 12/02	11:27	H71490	33	76.8	75	F	MatA	3.67	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
10	April 12/02	11:35	H71404	35	65.5	74	M	MatP	3.97	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
11	April 12/02	11:44	H71491	42	76.8	71	F	MatA	2.7	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
12	April 12/02	12:45	H71492	46	76.8	71	F	MatA	3.01	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
13	April 12/02	12:55	H71406	36	65.5	77	M	MatP	4.22	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
14	April 12/02	16:10	H71407	49	65.5	74	M	MatP	3.56	47 45.53	54 12.49	20	WI	47 35.03	54 17.60	40	17:00
15	April 12/02	16:26	H71408	46	65.5	72	M	MatP	3.05	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
16	April 12/02	16:46	H71493	47	76.8	70	F	MatA	2.6	47 45.53	54 12.49	20	HB	47 37.03	54 00.77	35	18:30
17	April 14/02	08:42	H71409	37	65.5	82	M	MatP	4.74	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
18	April 14/02	08:51	H71410	50	65.5	72	M	MatP	3.4	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
19	April 14/02	09:00	H71494	48	76.8	74	F	P Spent	3	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20

ID	Date of Capture	Time of Surgery	External Tag #	Code	Freq.	Length (cm)	Sex	Maturity	Weight (kg)	Catch Location			Release Location				Time of Release
										Lat.	Long.	Depth	Area	Lat.	Long.	Depth	
20	April 14/02	09:07	H71411	54	65.5	58	M	MatP	1.6	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
21	April 14/02	09:12	H71495	49	76.8	58	F	MatA	1.81	47 45.89	54 12.68	20	HB	47 37.03	54 00.77	35	19:20
22	April 14/02	09:19	H71412	57	65.5	59	M	MatP	1.93	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
23	April 14/02	09:24	H71413	66	65.5	73	M	P Spent	3.35	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
24	April 14/02	10:40	H71414	78	65.5	87	M	MatP	5.88	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
25	April 14/02	10:47	H71415	90	65.5	60	M	MatP	1.71	47 45.89	54 12.68	20	WI	47 35.03	54 17.60	40	18:00
26	April 14/02	10:57	H71496	54	76.8	72	F	MatA	3.12	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20
27	April 14/02	11:05	H71416	68	65.5	60	M	MatP	1.82	47 45.89	54 12.68	20	WO	47 45.54	54 12.36	20	13:20

APPENDIX 2 – Observation data for cod tagged at the Bar Haven grounds in April 2003.

OBSERVATION SHEET

ID	Date of Capture	Time of Surgery	External Tag #	Code	Freq.	Length (cm)	Sex	Maturity	Weight (kg)	Catch Location			Release Location				Time of Release
										Lat.	Long.	Depth	Area	Lat.	Long.	Depth	
1	April 9/03	11:35	H71026	46	76.8	75	F	MatA	3.748	4744.39	5411.58	50	BH	4744.39	5411.61	60	12:30
3	April 9/03	11:45	H71027	54	65.5	66	M	MatP	2.576	4744.39	5411.58	50	BH	4744.39	5411.61	60	12:30
4	April 10/03	14:35	H71032	32	65.5	65	M	MatP	2.8	4744.3	5411.79	40	BH	4744.37	5411.76	50	14:45
5	April 10/03	14:30	H71030	107	76.8	77	F	MatA	3.78	4744.3	5411.79	40	BH	4744.37	5411.76	50	14:45
7	April 11/03	12:43	H71033	102	76.8	70	F	MatA	2.72	4744.26	5411.77	30	BH	4744.37	5411.58	50	14:18
6	April 11/03	12:53	H71035	46	65.5	65	M	MatP	2.35	4744.26	5411.77	30	BH	4744.37	5411.58	50	14:18
2	April 15/03	12:47	H71038	37	65.5	66	M	MatP	2.65	4744.63	5413.1	40	BH	4744.43	5412.63	40	13:30
8	April 15/03	12:52	H71039	31	76.8	71	F	MatA	3.406	4744.63	5413.1	40	BH	4744.43	5412.63	40	13:30
2	April 15/03	12:57	H71040	90	76.8	69	F	MatA	3.24	4744.63	5413.1	40	BH	4744.43	5412.63	40	13:30

APPENDIX 3 – Relocation details for acoustically tagged cod released in 2002 and 2003.

RELOCATION SHEET

Last updated July 18/03

Date	Time	Code	Frequency	Area	Latitude	Longitude	Notes	Origin	Size
April 18/02	09:56	90	76.8	WO	47 45.92	54 12.89	First Listen	WO	S
April 18/02	09:56	102	76.8	WO	47 45.92	54 12.89		WO	L
April 18/02	10:33	50	65.5	WO	47 45.39	54 12.32		WO	L
April 18/02	10:33	66	76.8	WO	47 45.39	54 12.32		WO	L
April 18/02	11:03	78	76.8	WO	47 45.84	54 12.92		WO	S
April 18/02	11:03	54	76.8	WO	47 45.84	54 12.92		WO	L
April 18/02	11:14	54	76.8	WO	47 45.87	54 12.96		WO	L
April 18/02	11:19	78	65.5	WO	47 45.76	54 12.88		WO	L
April 18/02	11:22	57	65.5	WO	47 45.70	54 12.84		WO	S
April 18/02	11:31	57	65.5	WO	47 45.55	54 12.75		WO	S
April 18/02	11:49	90	76.8	WO	47 46.03	54 12.89		WO	S
April 18/02	11:49	54	76.8	WO	47 46.03	54 12.89		WO	S
April 18/02	11:53	102	76.8	WO	47 46.00	54 12.84		WO	L
April 18/02	12:13	68	76.8	WO	47 45.66	54 12.54		WO	S
April 18/02	12:28	50	65.5	WO	47 45.33	54 12.27		WO	L
April 18/02	13:49	90	76.8	WO	47 46.08	54 12.73		WO	S
April 18/02	13:56	102	76.8	WO	47 45.95	54 12.70		WO	L
April 18/02	14:32	48	76.8	WO	47 45.53	54 13.39		WO	L
April 18/02	14:32		65.5	WO	47 45.53	54 13.39	No Code	WO	
April 18/02	15:04	37	65.5	WO	47 45.44	54 13.73		WO	L
April 18/02	15:18	48	76.8	WO	47 45.50	54 13.38		WO	L
April 18/02	15:20	37	65.5	WO	47 45.47	54 13.35		WO	L
April 19/02	10:36	48	76.8	WO	47 45.49	54 13.36			
April 19/02	10:36		65.5	WO	47 45.49	54 13.36	No Code		
April 19/02	10:56	48	76.8	WO	47 45.30	54 13.41		WO	L

April 19/02	11:07	37	65.5	WO	47 45.37	54 13.69		WO	L
April 19/02	11:07	48	76.8	WO	47 45.37	54 13.69		WO	L
April 19/02	11:23	57	65.5	WO	47 44.88	54 12.99		WO	S
April 19/02	11:34	102	76.8	WO	47 46.03	54 12.71		WO	L
April 19/02	11:42	54	76.8	WO	47 45.82	54 12.67		WO	L
April 19/02	11:42		65.5	WO	47 45.82	54 12.67	No Code		
April 19/02	11:54	50	65.5	WO	47 45.62	54 12.57		WO	L
April 19/02	11:56	66	76.8	WO	47 45.59	54 12.56		WO	L
April 19/02	12:13	40	65.5	WO	47 45.28	54 12.33	Unknown Code		
April 19/02	12:13	66	76.8	WO	47 45.28	54 12.33		WO	L
April 19/02	12:16	66	65.5	WO	47 45.22	54 12.30		WO	L
April 19/02	12:34	77	65.5	WO	47 45.19	54 12.02	Unknown Code		
April 19/02	12:39	66	65.5	WO	47 45.12	54 11.97		WO	L
April 19/02	13:13	102	76.8	WO	47 46.09	54 12.65		WO	L
April 19/02	13:13	54	76.8	WO	47 46.09	54 12.65		WO	L
April 19/02	13:24	57	65.5	WO	47 45.85	54 12.60		WO	S
April 19/02	13:33	66	76.8	WO	47 45.65	54 12.54		WO	L
April 19/02	14:15	102	76.8	WO	47 45.95	54 13.03		WO	L
April 19/02	14:15	57	65.5	WO	47 45.95	54 13.03		WO	S
April 19/02	14:19	54	76.8	WO	47 45.92	54 13.01		WO	L
April 19/02	14:50	90	76.8	WO	47 46.69	54 12.44		WO	S
April 19/02	14:50	54	65.5	WO	47 46.69	54 12.44		WO	S
April 20/02	10:40	102	76.8	WO	47 45.85	54 12.79		WO	L
April 20/02	10:41	37	65.5	WO	47 45.87	54 12.78		WO	L
April 20/02	10:43	57	65.5	WO	47 45.89	54 12.77		WO	S
April 20/02	10:43		65.5	WO	47 45.89	54 12.77	No Code		
April 20/02	11:27	54	65.5	WO	47 46.45	54 12.69		WO	S
April 20/02	11:38	60	76.8	WO	47 46.62	54 12.58		WO	S
April 20/02	11:39	102	76.8	WO	47 46.64	54 12.56		WO	L
April 20/02	11:41	90	76.8	WO	47 46.66	54 12.55		WO	S
April 20/02	11:43	**112**	76.8	WO	47 46.69	54 12.52	Unknown Code		

April 20/02	16:01	114	76.8	WI	47 34.92	54 17.69		WI	S
April 20/02	16:01		65.5	WI	47 34.92	54 17.69	No Code		
April 20/02	16:17	34	76.8	WI	47 35.03	54 17.66		WI	L
April 20/02	16:26	34	76.8	WI	47 35.19	54 17.82		WI	L
April 20/02	16:44	96	65.5	WI	47 34.87	54 17.42		WI	S
April 20/02	16:51	107	65.5	WI	47 35.21	54 17.32		WI	S
April 22/02	10:10	47	76.8	HB	47 37.00	54 00.80	Heard by Shamook	HB	L
April 22/02	12:37	57	65.5	WO	47 46.62	54 12.55		WO	S
April 22/02	12:37		65.5	WO	47 46.62	54 12.55	No Code		
April 22/02	12:37		76.8	WO	47 46.62	54 12.55	No Code		
April 22/02	12:37		76.8	WO	47 46.62	54 12.55	No Code		
April 22/02	12:49	60	76.8	WO	47 46.39	54 12.71		WO	S
April 22/02	12:56	**106**	65.5	WO	47 46.28	54 12.65	Unknown Code		
April 22/02	13:08	78	65.5	WO	47 45.91	54 12.70		WO	L
April 22/02	14:01	54	65.5	WO	47 46.66	54 12.54		WO	S
April 22/02	14:02	90	76.8	WO	47 46.66	54 12.54		WO	S
April 22/02	14:05	3	65.5	WO	47 46.59	54 12.55	Unknown Code		
April 23/02	15:00			Clattice Hr			Listened over aggregation in 100m hole - NO PINGS		
April 25/02	09:02	54	65.5	WO	47 46.74	54 12.49		WO	S
April 25/02	09:03	90	76.8	WO	47 46.72	54 12.50		WO	S
April 25/02	09:07	60	76.8	WO	47 46.67	54 12.52		WO	S
April 25/02	09:13	60	76.8	WO	47 46.37	54 12.72		WO	S
April 25/02	09:13	54	65.5	WO	47 46.37	54 12.72		WO	S
April 25/02	10:21	37	65.5	WO	47 45.68	54 12.49		WO	L
April 25/02	10:31	37	65.5	WO	47 45.38	54 12.34		WO	L
April 25/02	10:31		76.8	WO	47 45.38	54 12.34	No Code		
April 25/02	10:32	54	76.8	WO	47 45.37	54 12.34		WO	L
April 25/02	10:38	37	65.5	WO	47 45.15	54 12.08		WO	L
April 25/02	10:39	54	76.8	WO	47 45.15	54 12.08		WO	L
April 25/02	10:49		65.5	WO	47 44.91	54 11.86	No Code (prob. 37)		

April 25/02	10:55	54	76.8	WO	47 44.89	54 11.87		WO	L
April 25/02	11:04	78	65.5	WO	47 44.63	54 11.69		WO	L
April 25/02	11:44	54	65.5	WO	47 44.91	54 11.36		WO	S
April 25/02	11:46	78	65.5	WO	47 44.91	54 11.37		WO	L
April 25/02	11:48	102	65.5	WO	47 44.90	54 11.38		WO	S
April 25/02	11:48	66	65.5	WO	47 44.90	54 11.38		WO	L
April 25/02	11:55	118	65.5	WO	47 45.13	54 11.20		HB	S
April 25/02	11:56	129	65.5	WO	47 45.12	54 11.20		WI	S
April 25/02	11:56	102	65.5	WO	47 45.12	54 11.20		WO	S
April 25/02	12:04	126	65.5	WO	47 45.32	54 11.38		HB	S
April 25/02	12:05	102	65.5	WO	47 44.32	54 11.38		WO	S
April 25/02	12:08	36	65.5	WO	47 45.31	54 11.40		HB	L
April 25/02	12:14	126	65.5	WO	47 45.47	54 11.57		HB	S
April 25/02	12:22	36	65.5	WO	47 45.58	54 11.23		HB	L
April 25/02	12:22	126	65.5	WO	47 45.58	54 11.23		HB	S
April 25/02	12:29	102	65.5	WO	47 45.34	54 11.10		WO	S
April 25/02	12:29	118	65.5	WO	47 45.34	54 11.10		HB	S
April 25/02	12:32	126	65.5	WO	47 45.33	54 11.11		HB	S
April 25/02	12:40	36	65.5	WO	47 45.73	54 10.97		HB	L
April 25/02	12:40		76.8	WO	47 45.73	54 10.97	No Code		
April 25/02	12:57	102	76.8	WO	47 45.89	54 10.77		WO	L
April 25/02	13:04	66	65.5	WO	47 46.12	54 10.78		WO	L
April 25/02	13:05	102	76.8	WO	47 46.11	54 10.78		WO	L
April 25/02	13:14	66	65.5	WO	47 46.38	54 10.70		WO	L
April 25/02	13:26	126	76.8	WO	47 46.58	54 10.53		HB	S
April 25/02	13:27	68	65.5	WO	47 46.58	54 10.54		WO	S
April 25/02	13:35	126	76.8	WO	47 46.81	54 10.50		HB	S
April 25/02	13:35	68	65.5	WO	47 46.81	54 10.50		WO	S
April 25/02	13:42	2	65.5	WO	47 46.98	54 10.35	Unknown Code		
April 25/02	13:48	68	65.5	WO	47 46.96	54 10.38		WO	S
April 25/02	14:03	126	76.8	WO	47 46.93	54 10.47		HB	S

April 25/02	14:10	68	65.5	WO	47 47.23	54 10.34		WO	S
April 25/02	14:24	68	65.5	WO	47 47.14	54 09.98		WO	S
April 25/02	14:48	48	76.8	WO	47 47.71	54 09.00		WO	L
April 25/02	14:55	48	76.8	WO	47 47.74	54 08.63		WO	L
April 25/02	15:00	48	76.8	WO	47 47.97	54 08.70		WO	L
April 25/02	15:08	48	76.8	WO	47 48.11	54 08.51		WO	L
April 25/02	15:15	48	76.8	WO	47 48.30	54 08.34		WO	L
April 25/02	15:56	49	76.8	WO	47 49.44	54 08.03		HB	S
April 25/02	16:12	49	76.8	WO	47 49.58	54 08.10		HB	S
April 25/02	16:20	49	76.8	WO	47 49.78	54 08.29		HB	S
April 30/02	10:49	68	76.8	WO	47 47.02	54 12.26		WO	S
April 30/02	11:00		65.5	WO	47 46.78	54 12.50	No Code		
April 30/02	11:01	90	76.8	WO	47 46.80	54 12.49		WO	S
April 30/02	11:01	68	76.8	WO	47 46.80	54 12.49		WO	S
April 30/02	11:46	50	65.5	WO	47 47.40	54 11.57		WO	L
April 30/02	11:52	50	65.5	WO	47 47.41	54 11.24		WO	L
May 2/02	09:10	68	76.8	WO	47 45.42	54 12.33		WO	S
May 2/02	09:29		76.8	WO	47 44.62	54 11.72	No Code		
May 2/02	09:37		76.8	WO	47 44.26	54 11.88	No Code		
May 2/02	11:11	50	65.5	WO	47 47.40	54 11.25		WO	L
May 2/02	11:17	50	65.5	WO	47 47.39	54 11.63		WO	L
May 21/02	18:22	68	65.5	Big Shoal	47 46.58	54 05.67		WO	S
May 22/02	?	160	65.5	WO	47 47.81	54 08.56	Caught by Eric Maye (549-2505) - 25m depth	HB	S
June 1/02		37	65.5	Beechy Flats			Caught by David Keating	WO	L
June 4/02	07:42		65.5	Sound Is.	47 46.81	54 09.26	No Code		
June 4/02	08:53	68	65.5	WO	47 44.22	54 11.89		WO	S
June 5/02	09:44	126	76.8	Bar Haven	47 49.09	54 10.97		HB	S
June 5/02	10:00		76.8	Bar Haven	47 41.88	54 10.64	No Code		
June 5/02	11:00	68	76.8	Bar Haven	47 41.90	54 13.02		WO	S
June 5/02	11:06	68	76.8	Bar Haven	47 42.00	54 13.42		WO	S

June 5/02	11:49	68	65.5	Bar Haven	47 44.21	54 11.89		WO	S
June 5/02	11:53	68	65.5	Bar Haven	47 44.33	54 12.32		WO	S
June 5/02	12:27	170	76.8	WO	47 45.387	54 13.111	BEACON TAG - Depth=35 m		
June 12/02	13:20		76.8	HB	47 37.10	54 00.87	No Code (prob. 47)		
June 12/02	13:33	47	76.8	HB	47 36.98	54 00.91		HB	L
June 12/02	13:49		76.8	HB	47 36.99	54 00.56	No Code (prob. 47)		
June 12/02	20:27	114	76.8	WI	47 34.92	54 17.69		WI	S
June 12/02	20:27	96	65.5	WI	47 34.92	54 17.69		WI	S
June 12/02	20:39	114	76.8	WI	47 34.95	54 17.63		WI	S
June 12/02	20:54	34	76.8	WI	47 35.03	54 17.85		WI	L
June 12/02	21:00	107	65.5	WI	47 35.22	54 17.31		WI	S
June 12/02	21:16	96	65.5	WI	47 34.87	54 17.14		WI	S
July 3/02	?	78	76.8	Cape St. Mary's			Caught by Albert Young (337-2213 or 337-2066)	WO	S
July 6/02		46	65.5	Cape St. Mary's			Caught by Robert Young	HB	L
July 30/02		35	65.5	Bread&Cheese	47 41.81	54 04.74	Caught by John Hickey	WI	L
Aug-02		35	76.8	CAPE SM			Caught by Martin McGrath	HB	L
Nov 13/02		42	76.8	Arnold's Cove	47 44.10	54 01.76	Caught by Roland Grandy 826-2112	WI	L
Nov 13/02		31	76.8	Fair Haven			Caught by Melvin Hickey 685-5098 or 463-0023		
Nov 16/02	08:50	?	65.5	BH	47 42.75	54 11.26	Unknown Code		
Nov 16/02	09:07	?	65.5	BH	47 42.80	54 11.01	Unknown Code		
Nov 16/02	10:40	?	65.5	BH	47 43.14	54 11.16	Hear 2 tags		
Nov 16/02	11:00	?	65.5	BH	47 43.16	54 11.14	Hear 2 tags		
Nov 16/02	11:26	?	76.8	BH	47 43.15	54 11.08	Unknown Code		
Nov 16/02				BH	47 43.15	54 10.93	XBT - Surface=6C, 60m=5.5C		
Nov 16/02	12:48	?	65.5	BH	47 42.51	54 11.18	Hear 2 tags		
Nov 16/02	12:48		76.8	BH	47 42.51	54 11.18	Hear 2 tags		
Nov 16/02	13:08	?	76.8	BH	47 42.54	54 11.18	Unknown Code		
Nov 16/02	13:08	?	65.5	BH	47 42.54	54 11.18	Unknown Code		

Nov 16/02	13:21	46	65.5	BH	47 42.48	54 11.04	Hear code from re-issued tag, in fish located in holding tank on deck		
Nov 16/02	13:37	46	65.5	BH	47 42.52	54 11.13	Hear code from re-issued tag, in fish located in holding tank on deck		
Nov 16/02	13:37	35	65.5	BH	47 42.52	54 11.13	Hear code from re-issued tag, in fish located in holding tank on deck		
Nov 16/02	13:50			BH	47 42.46	54 11.22	Released 4 fish (42F, 46M, 35F, 35M)		
Nov 16/02	13:54	35	65.5	BH	47 42.45	54 11.17	Listening for released fish		
Nov 16/02	13:54	46	65.5	BH	47 42.45	54 11.17	Listening for released fish		
Nov 16/02	13:54	35	76.8	BH	47 42.45	54 11.17	Listening for released fish		
Nov 16/02	13:54	?	76.8	BH	47 42.45	54 11.17	Listening for released fish		
Nov 16/02	14:46			BH	47 40.97	54 12.04	Listened 1 mile S of B.H. Bank, no tagged fish but many small groups all along bank		
Nov 16/02	14:33			BH	47 44.05	54 11.37	Listened at Corner Bank, no tagged fish		
Nov 16/02	14:48			BH	47 44.38	54 11.56	Listened at Corner Bank, no tagged fish		
Nov 16/02	16:15			BH	47 42.45	54 11.22	Released 5 fish (37M, 78F, 160M, 103F, 168M)	BH (Nov)	
Nov 20/02		54	65.5	WO			Caught by Gary Hussey 549-2614 - SE of Woody Is., 30 fathoms depth	WO	S
Nov 24/02		90	76.8	WO			Caught by Mike Williams, fish length 24", 180 ft depth	WO	S
Nov 30/02		102	76.8	Near Haystack Bank	4734.85	5358.87	Caught by Cecil Penney, Arnold's Cove, 463-2157	WO	L

Dec 1/02		37	65.5	Bar Haven Bank	4742.5	5411.3	Caught by Bernard Leonard, (709) 463-2163	BH (Nov)	72
Dec 6/02		107	76.8	North Harbour	4747.42	5404.2	Caught by Dennis Stacey, 857-2305, cell 832-7061, fish 24" and 5lb	HB	58
Dec 7/02		46	65.5	BH (Saturday Ledge)	4741.9	5411.5	Caught by Eugene Murphy, among 3000lb fish caught (Tag returned 2nd time)	BH (Nov)	59
Dec 7/02		46	76.8		4734.85	5358.88	Caught by Arthur Boutcher, Little Harbour East, Plac. Bay, (709) 465-3391, gillnet, 50 fathoms	WI	71
Jan 4/03		32	76.8	BH (Western Bay)	4742	5413.7	Caught by Daisy Parsons 463-8863, Western Bay, Bar Haven, 60 fathoms	HB	71
April 2/03	12:41	114	77	WI	4734.92	5417.74	First listen of 2003, found all 4 tags on bottom at same locations near White Islands.	WI	60
April 2/03	12:46	34	77	WI	4735	5417.68		WI	85
April 2/03	12:56	107	65	WI	4735.21	5417.33		WI	61
April 2/03	13:01	96	65	WI	4734.82	5417.39		WI	60
April 3/03	11:08	7	65	BH	4744.12	5411.22		HB	76
April 8/03		35	77	WO	4746.58	5409.11		BH(Nov)	59
April 8/03		35	77	WO	4746.03	5410.43		BH(Nov)	59
April 8/03		35	77	WO	4746.09	5410.26		BH(Nov)	59
April 9/03	12:30			BH	4744.39	5411.61	Released 2 fish (54M and 46F)	BH (03)	
April 9/03	15:41	54	65	BH	4744.35	5411.56		BH (03)	66
April 9/03	21:27	54	65	BH	4744.37	5411.66		BH (03)	66
April 10/03	10:00	160	77	BH	4742.36	5411.82		WI	57
April 10/03	10:03	160	77	BH	4742.33	5411.66		WI	57
April 10/03	10:08	160	77	BH	4742.65	5411.81		WI	57

April 10/03	10:21	160	77	BH	4742.59	5411.65		WI	57
April 10/03	10:39	7	65	BH	4743.92	5411.38		HB	76
April 10/03	10:44	54	65	BH	4744.1	5411.34		BH (03)	66
April 10/03	10:44	7	65	BH	4744.1	5411.34		HB	76
April 10/03	10:44	3	65	BH	4744.1	5411.34	Unknown Code		
April 10/03	10:48	54	65	BH	4744.13	5411.73		BH (03)	66
April 10/03	11:01	54	65	BH	4744.53	5411.41		BH (03)	66
April 10/03	11:01	3	65	BH	4744.53	5411.41	Unknown Code		
April 10/03	11:07	7	65	BH	4744.56	5410.82		HB	76
April 10/03	11:29	18	65	BH	4744.38	5411.57	Unknown Code		
April 10/03	11:29	54	65	BH	4744.38	5411.57		BH (03)	66
April 10/03	14:45			BH	4744.37	5411.76	Released 2 fish (32M and 107F)	BH (03)	
April 10/03	15:22	7	65	BH	4744.17	5411.09		HB	76
April 10/03	16:27	32	65	BH	4744.35	5411.75		BH (03)	65
April 10/03	16:27	107	77	BH	4744.35	5411.75		BH (03)	77
April 10/03	18:04	32	65	BH	4744.42	5412.18		BH (03)	65
April 10/03	18:04	107	77	BH	4744.42	5412.18		BH (03)	77
April 10/03	18:07	32	65	BH	4744.4	5411.91		BH (03)	65
April 10/03	18:07	107	77	BH	4744.4	5411.91		BH (03)	77
April 10/03	18:12	32	65	BH	4744.25	5411.76		BH (03)	65
April 10/03	18:12	27		BH	4744.25	5411.76	Unknown Code		
April 10/03	18:12	28		BH	4744.25	5411.76	Unknown Code		
April 10/03	18:12	107	77	BH	4744.25	5411.76		BH (03)	77
April 10/03	18:19	32	65	BH	4744.42	5411.54		BH (03)	65
April 10/03	18:24	107	77	BH	4744.46	5411.53		BH (03)	77
April 10/03	18:24	64		BH	4744.46	5411.53	Unknown Code		
April 10/03	18:27	32	65	BH	4744.46	5411.28		BH (03)	65
April 10/03	18:34	7	65	BH	4744.45	5410.49		HB	76
April 10/03	18:34	54	65	BH	4744.45	5410.49		BH (03)	66
April 10/03	18:41	7	65	BH	4744.47	5410.47		HB	76
April 10/03	18:44	7	65	BH	4744.32	5410.51		HB	76

April 11/03	09:54	115	65	BH	4744.53	5412.18	Unknown Code		
April 11/03	10:00	32	65	BH	4744.44	5411.9		BH (03)	65
April 11/03	10:04	107	77	BH	4744.2	5411.64		BH (03)	77
April 11/03	10:18	20	65	BH	4744.32	5411.3	Unknown Code		
April 11/03	10:21	107	77	BH	4744.33	5411.53		BH (03)	77
April 11/03	10:26	7	65	BH	4744.3	5410.47		HB	76
April 11/03	10:32	32	65	BH	4744.36	5411.64		BH (03)	65
April 11/03	10:36	32	65	BH	4744.59	5411.7		BH (03)	65
April 11/03	10:47	107	77	BH	4744.82	5411.73		BH (03)	77
April 11/03	10:52	32	65	BH	4744.79	5412.08		BH (03)	65
April 11/03	10:54	32	65	BH	4744.61	5412.07		BH (03)	65
April 11/03	10:57	32	65	BH	4744.33	5412.08		BH (03)	65
April 11/03	11:04	32	65	BH	4744.26	5411.95		BH (03)	65
April 11/03	11:04	27	65	BH	4744.26	5411.95	Unknown Code		
April 11/03	11:11	107	77	BH	4744.3	5411.78		BH (03)	77
April 11/03	13:37	7	65	BH	4744.17	5411.21		HB	76
April 11/03	13:48	107	77	BH	4744.26	5411.68		BH (03)	77
April 11/03	14:18			BH	4733.37	5411.58	Released 2 fish (46M and 102F)	BH (03)	
April 12/03	16:13	170	77	BH	4745.38	5413.05	BEACON		
April 12/03	16:31	32	65	BH	4744.16	5412.22		BH (03)	65
April 12/03	16:35	32	65	BH	4744.29	5412.54		BH (03)	65
April 12/03	16:43	78	77	BH	4744.48	5411.38		BH (02)	70
April 12/03	16:48	7	65	BH	4744.18	5410.89		HB	76
April 13/03	11:03	107	77	BH	4743.79	5411.54		BH (03)	77
April 13/03	11:19	7	65	BH	4744.03	5410.92		HB	76
April 13/03	11:30	36	77	BH	4744	5411.52		HB	71
April 13/03	12:12	7	65	BH	4744.2	5411.2		HB	76
April 13/03	12:24	7	65	BH	4744.42	5410.86		HB	76
April 15/03	13:30			BH	4744.43	5412.63	Released 3 fish (37M, 31F and 90F)	BH (03)	
April 16/03	09:55	7	65	BH	4744.16	5410.87		HB	76

April 16/03	10:17	31	77	BH	4745.04	5411.9		BH (03)	71
April 16/03	10:21	31	77	BH	4745.21	5412.25		BH (03)	71
April 16/03	10:25	78	77	BH	4745.38	5412.58		BH (02)	70
April 16/03	10:28	78	77	BH	4745.64	5412.44		BH (02)	70
April 16/03	10:30	78	77	BH	4745.65	5412.21		BH (02)	70
April 16/03	10:34	170	77	BH	4745.56	5412.97	BEACON		
April 16/03	10:40	78	77	BH	4745.98	5412.77		BH (02)	70
April 16/03	11:19	37	65	BH	4744.49	5412.77		BH (03)	66
April 16/03	11:21	37	65	BH	4744.39	5412.5		BH (03)	66
April 16/03	12:30	37	65	BH	4744.39	5412.44		BH (03)	66
April 16/03	12:40	36	65	BH	4744.36	5412.73		HB	77
April 16/03	12:40	36	77	BH	4744.36	5412.73		HB	71
April 16/03	12:50	107	77	BH	4744.16	5411.71		BH (03)	77
April 16/03	12:57	2		BH	4744.17	5411.33	Unknown Code		
April 16/03	13:04	107	77	BH	4744	5411.52		BH (03)	77
April 16/03	13:06	107	77	BH	4744.01	5411.85		BH (03)	77
April 16/03	13:09	107	77	BH	4743.82	5412.1		BH (03)	77
April 16/03	13:12	107	77	BH	4743.76	5411.72		BH (03)	77
April 16/03	13:14	107	77	BH	4743.76	5411.43		BH (03)	77
April 16/03	13:26	50	65	BH	4744.22	5412.54		WO	72
April 16/03	13:31	36	77	BH	4744.48	5413.05		HB	71
April 16/03	13:34	36	77	BH	4744.63	5413.34		HB	71
April 16/03	13:37	36	77	BH	4744.72	5413.63		HB	71
April 16/03	13:47	90	77	BH	4745.32	5413.21		BH (03)	69
April 16/03	13:50	170		BH	4745.35	5413.02	BEACON		
April 16/03	13:52	78	77	BH	4745.73	5413.04		BH (02)	70
May 1/03		36	77	BH	4743.7	5411.6	Caught by Rick Senior, 443-2593, Red Harbour,NL, A0E 2R0	HB	71
May 12/03	15:22	107	77	BH	4743.77	5411.67		BH (03)	77
May 12/03	15:30	107	77	BH	4743.86	5411.97		BH (03)	77
May 12/03	16:31	170	77	BH	4745.36	5413.06	BEACON	BEACON	

May 12/03	16:54	90	77	BH	4745.12	5411.56		BH (03)	69
May 13/03	09:36	107	77	BH	4743.85	5411.94		BH (03)	77
May 13/03	11:22	90	77	BH	4745.29	5411.38	strong signal	BH (03)	69
May 13/03	11:26	90	77	BH	4745.19	5411.23		BH (03)	69
May 13/03	12:12	7	65	BH	4744.37	5410.92		HB	76
May 13/03	12:49	107	77	BH	4743.72	5411.84	listened over aggregation	BH (03)	77
May 13/03	15:39	107	77	BH	4743.68	5411.82	listened over aggregation	BH (03)	77
May 13/03	16:40	107	77	BH	4743.74	5411.83	listened over aggregation	BH (03)	77
May 14/03	09:49	107	77	BH	4743.78	5411.8	listened over aggregation	BH (03)	77
May 14/03	10:43	107	77	BH	4743.65	5411.71		BH (03)	77
May 14/03	10:47	107	77	BH	4743.61	5412.03	very weak signal	BH (03)	77
May 14/03	10:56	107	77	BH	4743.83	5411.72		BH (03)	77
May 14/03	11:03	57	65	BH	4744.06	5411.39	could be false code	WO	59
May 14/03	11:41	7	65	BH	4744.26	5411.18		HB	76
May 14/03	11:49	7	65	BH	4744.1	5411.16		HB	76
May 14/03	11:52	79	65	BH	4744.07	5411.4	Unknown Code		
May 14/03	11:52	31	65	BH	4744.07	5411.4	could be false code		
May 14/03	12:13	1	65	BH	4744.25	5411.3	Unknown Code		
May 14/03	12:19	7	65	BH	4743.95	5411.25		HB	76
May 14/03	12:19	2	65	BH	4743.95	5411.25	Unknown Code		
May 14/03	13:59	102	77	BH	4747.41	5410.73		BH (03)	70
May 14/03	14:12	102	77	BH	4747.65	5410.89	strong signal	BH (03)	70
May 14/03	14:34	126	77	BH	4747.56	5410.96		HB	60
May 14/03	14:50	52	65	BH	4747.58	5411.24	Unknown Code		
May 14/03	14:55	102	77	BH	4747.64	5410.94		BH (03)	70
May 14/03	15:02	15	77	BH	4747.74	5410.37	Unknown Code		
May 14/03	15:07	102	77	BH	4747.68	5410.65		BH (03)	70
May 14/03	15:31	102	65	BH	4746.94	5412.26		WO	60
May 14/03	16:22	31	77	BH	4745.26	5412.23		BH (03)	71
May 14/03	17:21	102	65	BH	4747.06	5412.31		WO	60
May 15/03	10:20	46	77	BH	4747.31	5410.37	very strong signal	BH (03)	75

May 15/03	10:25	65	77	BH	4747.15	5409.98	Unknown Code		
May 15/03	10:30	31	65	BH	4747.02	5410.36	Unknown Code		
May 15/03	10:36	46	77	BH	4747.12	5410.45		BH (03)	75
May 15/03	10:40	46	77	BH	4747.17	5410.54	very strong signal	BH (03)	75
May 15/03	10:49	46	77	BH	4747.44	5410.23		BH (03)	75
May 15/03	10:49	17	77	BH	4747.44	5410.23	Unknown Code		
May 15/03	10:49	102	77	BH	4747.44	5410.23	strong signal	BH (03)	70
May 15/03	13:11	107	77	BH	4743.76	5411.69	many small groups	BH (03)	77
May 15/03	13:47	31	77	BH	4745.45	5412.23	strong signal	BH (03)	71
May 15/03	15:56	102	65	BH	4747.13	5412.55		WO	60
April 16/03	08:11	31	77	BH	4745.38	5412.29		BH (03)	71
April 16/03	11:13	102	65	BH	4747.17	5412.54		WO	60
July 14/03		118	65	White Is. Bank	4718.34	5421.34	Caught by Gerome Ward of SE Bight, 428-3321, Gillnet	HB	60

APPENDIX 4 – Sampling information of fishing sets taken from 1998-2003 at the Bar Haven spawning grounds in Placentia Bay, Newfoundland.

Set ID	Date	Location		Depth (m)	*N*	Males	Females
1	18 Apr 1998	47° 45.10'N	54°13.40'W	48	129	124	5
2	19 Apr 1998	47° 44.80'N	54°10.70'W	125	71	27	44
3	17 May 1998	47° 44.73'N	54°12.00'W	63	25	13	12
4	28 May 1998	47° 43.70'N	54°10.99'W	100	31	13	18
5	29 Jun 1998	47° 43.50'N	54°10.50'W	37	43	20	23
6	1 Jul 1998	47° 43.50'N	54°10.50'W	37	32	21	11
7	7 Apr 1999	47° 41.27'N	54°09.25'W	30	38	16	22
8	8 Apr 1999	47° 44.16'N	54°12.23'W	19	19	5	14
9	8 Apr 1999	47° 44.41'N	54°12.50'W	24	28	24	4
10	9 Apr 1999	47° 44.21'N	54°11.92'W	14	25	14	11
11	9 Apr 1999	47° 44.47'N	54°11.66'W	50	16	11	5
12	9 Apr 1999	47° 45.25'N	54°11.10'W	28	27	11	16
13	9 Apr 1999	47° 46.43'N	54°09.73'W	53	21	12	9
14	9 Apr 1999	47° 45.87'N	54°13.16'W	35	20	18	2
15	13 Apr 1999	47° 45.68'N	54°13.01'W	38	67	50	17
16	4 May 1999	47° 41.80'N	54°11.64'W	39	18	9	9
17	4 May 1999	47° 42.42'N	54°11.25'W	44	19	8	11
18	4 May 1999	47° 40.98'N	54°12.03'W	35	13	9	4
19	3 Apr 2000	47° 45.25'N	54°13.20'W	30	54	35	19
20	14 Apr 2000	47° 44.34'N	54°11.74'W	25	53	31	22
21	21 May 2000	47° 42.44'N	54°11.23'W	44	19	8	11
22	6 Apr 2001	47° 40.80'N	54°16.41'W	30	51	22	29
23	11 Apr 2001	47° 41.75'N	54°14.11'W	10	57	30	27
24	12 Apr 2001	47° 41.60'N	54°14.20'W	12	58	35	23
25	7 Apr 2002	47° 45.69'N	54°13.76'W	20	22	18	4
26	9 Apr 2002	47° 45.04'N	54°12.35'W	60	126	70	56
27	11 Apr 2002	47° 46.60'N	54°12.62'W	20	36	18	18
28	11 Apr 2002	47° 45.44'N	54°12.44'W	24	66	40	26
29	11 Apr 2002	47° 46.56'N	54°12.63'W	19	51	27	24
30	3 Apr 2003	47° 44.80'N	54°11.64'W	29	50	35	15
31	3 Apr 2003	47° 44.43'N	54°11.56'W	37	49	26	23
32	3 Apr 2003	47° 43.33'N	54°11.80'W	30	10	7	3
33	4 Apr 2003	47° 46.60'N	54°09.51'W	35	52	33	19
34	5 Apr 2003	47° 49.39'N	54°07.85'W	50	59	33	26
35	9 Apr 2003	47° 46.18'N	54°08.28'W	63	152	75	77
36	9 Apr 2003	47° 44.42'N	54°11.59'W	37	50	23	27
37	10 Apr 2003	47° 44.37'N	54°11.69'W	30	66	33	33
38	11 Apr 2003	47° 44.28'N	54°11.76'W	20	66	36	30
39	15 Apr 2003	47° 44.70'N	54°13.00'W	30	57	24	33
40	15 Apr 2003	47° 45.73'N	54°12.59'W	30	50	25	25

41	15	Apr 2003	47° 44.47'N	54°12.60'W	42	49	25	24
42	15	Apr 2003	47° 45.47'N	54°12.59'W	25	62	32	30